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Assessment of 4X5Y Haddock (*Melanogrammus aeglefinus*) in 2016

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Landings of Haddock in Northwest Atlantic Fisheries Organization Divisions (NAFO) 4X5Y in the 2014/15 and 2015/16 fishing years were 2,825 tonnes (t) and 2,926 t, respectively, relative to a quota of 5,100 t. The Fisheries and Oceans Canada (DFO) Summer Research Vessel (RV) survey biomass index in 2015 and 2016 was 69,800 t and 62,700 t, respectively; both years are above the short (5 year: 48,193 t) and long-term (since 1970: 55,470 t) averages. For both the commercial fishery and the DFO Summer RV survey, values for the mean weight-at-age and length-at-age show a decline from the early 1990s to the mid-2000s and then a levelling off or a modest increase, followed by the lowest weight-at-age for many ages occurring in 2015. The beginning of year spawning stock biomass for 2016 was estimated to be 33,770 t using a Virtual Population Analysis (VPA), which is above the established biomass limit reference point (B_{lim}) of 19,700 t and the long-term average of 32,258 t. The preliminary estimates for the 2013 year class at Age 1 remain extraordinarily high for this stock at 264 million recruits, and the estimate for the 2014 year class (Age 1 in 2015) is 74 million, above the long-term geometric mean for Age 1 of 20 million recruits. The estimated fishing mortality (F) for ages 6 to 10 in 2015 was 0.05 for 4X5Y Haddock, therefore below the fishing mortality reference point (F_{ref}) in both the Healthy Zone (F_{ref}=0.25) and Cautious Zone (F=0.15). In the absence of an Upper Stock Reference point, it cannot be distinguished whether the stock is in the Cautious or Healthy Zone; therefore, deterministic and stochastic projections were conducted using both F_{ref}=0.25 and F=0.15 scenarios. Under the various harvest scenarios examined, the spawning stock biomass is projected to increase to around 100,000 t, double the previous peak observed from the 1985 to 2015 time series. The 2013 year class at Age 4 is expected to contribute 61% of the 1+ population biomass in 2017 and 59% in 2018 (Age 5). Notably, the 2013 year class appears to be much stronger than anything previously observed, but there is uncertainty around this estimate given the retrospective pattern in the model, the small number of observations in both the survey and fishery, and the apparent mismatch between survey abundance estimates and the VPA in recent years. The future performance of the 2013 and 2014 year classes will impact the stock dynamics.

INTRODUCTION

Haddock (*Melanogrammus aeglefinus*) are found on both sides of the North Atlantic; they occur in the northwestern Atlantic from southwest Greenland to Cape Hatteras. A major stock exists on the western Scotian Shelf and in the Bay of Fundy (Northwest Atlantic Fisheries Organization (NAFO) Divisions 4X5Y) (Figure 1). Growth rates of Haddock in the Bay of Fundy (4Xqrs5Y) are higher than those of Haddock on the western Scotian Shelf (4Xmnop) (Hurley et al. 1998) so that separate Age Length Keys (ALKs) have been used in the past for calculating the fishery catch-at-age (CAA) and survey indices of abundance. Major spawning grounds are found on Browns Bank, and peak spawning occurs from April to May (Page and Frank 1989), although it can occur as early as February if conditions are favourable (Head et al. 2005). A seasonal spawning closure was implemented on Browns Bank in 1970, which is closed from February 1st to June 15th (Halliday 1988).

Haddock in NAFO Divisions 4X5Y (herein after referred to as 4X5Y Haddock) are harvested as part of a mixed, multi-species fishery that includes Atlantic Cod, Halibut, redfish, Pollock, White Hake, and flounders. The Haddock fishery is limited by the incidental catch of Atlantic Cod, which has strict bycatch limits. The mandatory use of a 130 mm square mesh cod end for bottom trawl was implemented in 1991 to allow for escapement of smaller fish; however, Haddock are also captured as bycatch in the redfish fishery, which uses smaller 100-112 mm diamond mesh cod ends.

The last assessment of the 4X5Y Haddock stock was conducted using data up to 2011 (Showell et al. 2013). A continuing strong retrospective pattern in the Sequential Population Analysis (SPA) model and poor model fit to survey indices led to a framework review. The recent framework review of 4X5Y Haddock occurred in two parts. The first part focused on commercial fishery and survey data inputs, which were evaluated during a meeting conducted at the Bedford Institute of Oceanography in Dartmouth, NS, on October 22, 2014, and documented in Stone and Hansen (2015). The second part took place at the Biological Station in St. Andrews, NB, from April 26-27, 2016, and focused on the model(s) used to determine stock status, reference points, risk analysis and the inter-framework assessment strategy (Wang et al. 2017).

The objectives of this regional peer review process were to:

- Evaluate biological and fishery information on 4X5Y Haddock stock status and characterize the uncertainty of the results. Specifically, provide information on distribution, biomass estimates, length and age composition, condition, highlighting trends over the long-term (length of assessment) and most recent period (5 years).
- Evaluate the current status of the stock relative to the adopted reference points.
- Evaluate the consequences of different harvest levels during the 2017/18 fishery on stock abundance and fishing mortality. Where possible, provide the following information:
    - For a range of total catch values, estimate the risk that fishing mortality rate (F) would exceed the reference level for when the stock is in the Healthy Zone (F_{ref}=0.25) and the recommended F for when the stock is in the Cautious Zone (F=0.15) in 2017 and 2018. Include a table showing the catches corresponding to low (25%), neutral (50%), and high (75%) probability that F would exceed F=0.25 and F=0.15.
    - For a range of total catch values in 2017 and 2018, estimate the probability that spawning biomass at the beginning of year 2018 and 2019 would remain stable or not increase by 10% from the previous year's level.

- Sensitivity analysis on the estimate of probability that the fishing mortality rate would exceed F=0.25 and F=0.15 in 2017/18 and the expected spawning biomass change under constant Total Allowable Catch (TAC).

This assessment includes the DFO Summer Research Vessel (RV) survey biomass index data up to 2016, as well as commercial landings data up to 2015. The stock is modeled using a Virtual Population Analysis (VPA) model and data framework as in Wang et al. (2017); the population model, projection, and risk analyses include 1985-2015 data.

THE FISHERY

COMMERCIAL LANDINGS

Reported annual landings of 4X5Y Haddock averaged 18,500 t during the 1970s and 19,800 t during the 1980s, with peaks occurring in the late 1960s and early 1980s (Table 1, Figure 2). Noteworthy is that from 1982-1984 the TAC peaked at 32,000 t but was quickly reduced to 4,600 t by 1989. In 1991 and 1992, there was no TAC for Haddock under a Management Plan that called for a bycatch fishery only, although landings exceeded 9,000 t during these years (Hurley et al. 2009). The TAC or 8,100 t established for the 12 month fishery in 1999 was extended to 9,800 t for the 15-month period ending March 31, 2000. The fishing year since then has been April 1st to March 31st. Annual landings dropped substantially in the 1990s and 2000s, averaging 6,681 t and 4,260 t, respectively. Since 2010, landings have been below 5,000 t and in 2014 and 2015 they were 2,718 t and 2,747 t, the lowest in the 40 year time series. The Fishing Year (FY) TAC (FY, April 1st - March 31st) was 7,000 t from 2006-2009, but it was subsequently reduced to 6,000 t for FYs 2010/2011 and 2011/2012 and to 5,100 t for FYs 2012/2013 through 2015/2016 (Table 1). Fishing year landings for 2014/2015 and 2015/2016 were 2,825 t and 2,926 t, respectively, well below the TAC.

Since the mid-1970s, the small mobile gear component (bottom trawl, Tonnage Class (TC) 1-3) has accounted for most of the total landings, with the exception of the early 1990s when the percentage taken by fixed gear (longline) was greater (Figure 3, Table 2). The percentage of landings from longline has steadily declined since 1994, whereas the small mobile gear share has increased. Over the past 10 years, small otter trawlers (TC 1-3) have taken an average of about 80% of the catch and longline vessels about 20%. There has been a declining trend in longline catches since 2011, with the 2015 catch representing only 4% of total landings (compared to 96% for mobile gear). Large otter trawlers (TC 4+) contributed 30-40% of total landings in the 1970s, but there are few left in the fishery at present (their contribution is currently < 1%). The contribution by the handline and gillnet sectors has also declined to very low levels (< 1%) since the late 1990s.

Since 2010, most landings have occurred during the first quarter (42%), followed by the third (25%), fourth (19%) and second (14%) quarters (Table 3). The change to an April-March fishing year in 2000 has led to an increase in the proportion of fish landed during January to March, a seasonal change that has helped to reduce the bycatch of cod (Hurley et al. 2009). This is also when the Georges Bank fishery for Haddock is closed (i.e. mid-February to May 31st), so there is likely a shift to fishing the 4X5Y stock at this time of year. Over the past decade, about 75% of total landings have been taken from Scotian Shelf statistical unit areas 4Xn and 4Xp (Figure 4). While the increase in 4Xn is largely a result of the winter (January-March) fishery, the increase in 4Xp reflects directing for larger Haddock in the deeper waters of the Fundian Channel where the bycatch of cod also tends to be lower (Hurley et al. 2009). Haddock landings in 4Xp remained high, contributing 45% of the total landings in 2015 and an average of 40% over the past five years (Figure 4).

Most of the 4X5Y Haddock fishery catch is currently taken on the Scotian Shelf (4Xmnop) by the mobile gear sector, with the majority of the remainder taken in the Bay of Fundy (4Xqrs5Y) by mobile gear (Table 4, Figure 5 and 6). Fixed gear catches from both the Bay of Fundy and Scotian Shelf regions remain low, contributing only 4% and <1%, respectively in 2015 (Table 4; Figure 6).

FISHERY CATCH-AT-AGE AND LENGTH/WEIGHT-AT-AGE

The 4X5Y Haddock fishery catch-at-age (CAA), weight-at-age (WAA), and length-at-age (LAA) was updated for 2015 (see Stone and Hansen 2015 for revision history). For CAA calculations, the length frequencies obtained by port samplers were grouped by Gear (Mobile, Fixed), Season (QTR or Half Year) and Area (Bay of Fundy: 4Xqrs5Y; Scotian Shelf: 4Xmnop). Age length keys (ALKs) were grouped by Area and Season (Qtr or Half Year). Annual length-weight relationships (a's and b's) for Haddock from the DFO Summer Research Survey were calculated separately for Bay of Fundy Strata (482-495) and Scotian Shelf Strata (470-481) and applied to matching sample areas for CAA determinations.

Ages were assigned by a single ager. As a routine check, the ager initially read the 4X5Y Haddock reference collection. A pair-wise comparison of ages showed high precision, 92.5% agreement in 2015 and little bias with an overall coefficient of variation of 1.42% (Appendix). These results were considered acceptable.

Catch-at-age (CAA) calculations for 2011, 2012 and 2013 included a separate category for Haddock catches from the 4X redfish fishery which uses a smaller cod end mesh size (i.e. 100-112 mm diamond mesh) and has a tendency to retain more small fish (i.e. ages 2-3). Haddock catches from the 4X redfish fishery increased from < 1% of total landings in the early 1990s to 8% by 2002, declined to < 2% in 2003-2004, then increased steadily reaching 15% in 2012 and 13% in 2013 before dropping off to 3% in 2015 (Figure 7). For 2011-2015, small mesh gear landings of Haddock were 325 t, 623 t, 460 t, 128 t, and 82 t, respectively. There were too few port samples available to size the small mesh catches in CAA calculations with the exception of 2011-2013.

The 4X5Y Haddock fishery CAA data for assessment modelling includes ages 1-14 for 1985-2015 (Table 5, Figure 8). This series shows the presence of some recent strong year classes (i.e. 2003, 2010, and the incoming 2013) and a reduction in the catches of Age 2 fish beginning in the early 1990s. The latter coincides with the mandatory use of 130 mm square mesh in 1991, but also there has been a decline in WAA and LAA during this period that has reduced the partial recruitment/selectivity of this age group (Table 6; Figure 9 and 10). In the 2015 fishery, the 2010 year class at Age 5 was predominant and represented 32% of the CAA followed by the 2011 year class at 27%. The 2003 year class, which made a significant contribution to the fishery back to 2006, represented only 0.5% of the 2015 fishery catch at Age 12. Noteworthy is that older fish (Age 10+) continue to appear in the time series up until 2015.

There have been changes in the catch at size by gear type (mobile vs. fixed) and area (Bay of Fundy vs. Scotian Shelf) over the 30 year time period (1985-2014), which could contribute to changes in selectivity and partial recruitment to the fishery (Figure 11). Not only are Haddock captured in the recent period (2010-2015) considerably smaller than they were in the past, but the contribution from the fixed gear sector has diminished. Fixed gear has generally captured larger fish than mobile gear.

Fishery mean weights-at-age (WAA, kg) and lengths-at-age (LAA, cm) for 2015 were calculated from the CAA application (Table 6, Figure 9 and 10). The weighting of WAA is done internally in the CAA workspace. Separate age length keys were used for Scotian Shelf and Bay of Fundy

samples to generate numbers-at-age that were then used for weighting the calculations of the overall fishery WAA. Both series indicated a declining trend in WAA and LAA from the early 1990s to mid-2000s and then either showed a modest increase or a leveling off in the recent period, followed by a decrease in 2015. While it is not clear what caused the declining trend over this time period, the effect on stock productivity is significant and has been discussed in previous assessments (Hurley et al. 2009, Mohn et al. 2010). In 2015, the mean weight-at-age for ages 1, 2, 3, 4, 5, 8, and 9 are the lowest in the time series (Table 6).

DFO SUMMER RESEARCH VESSEL SURVEY UPDATE

CATCH DISTRIBUTION, INDICIES OF ABUNDANCE, LENGTH/WEIGHT-AT-AGE

Fisheries and Oceans Canada (DFO) has conducted a stratified random bottom trawl survey of the Scotian Shelf and Bay of Fundy every summer since 1970. Over the 47 year DFO Summer RV survey time series (1970-2016), the main areas of Haddock abundance have been on Browns Bank, Baccaro Bank and the outer Bay of Fundy area (Figure 12).

Due to differences in growth rates (Hurley et al. 1998), the total biomass index is calculated separately for the Bay of Fundy (Strata 482-495) and western Scotian Shelf (Strata 470-481) for 1970-2016 (Figure 13). While both indices show high variability over the time series, the general pattern is one of decreasing biomass from the mid-1980s to mid-1990s, followed by a period of increasing biomass through the late 1990s to the early-2000s, then lower biomass from 2004-2013, and then an increase (Table 7, Figure 14). 2015 is the first year that the total biomass index has been above the long term mean since 2011 for the western Scotian Shelf and since 2003 for the Bay of Fundy. In 2015, the total biomass estimate for the Bay of Fundy was 32,200 t and for the Scotian Shelf it was 37,600 t, the total biomass index in 2015 for both areas combined was 69,800 t. In 2016, the total biomass estimate for the Bay of Fundy was 38,000 t and for the Scotian Shelf it was 24,700 t. The total biomass index in 2016 for both areas combined was 62,700 t, remaining above the time series average of 55,400 t.

The age-specific indices of abundance (total numbers at age) for 1970-2015 were calculated separately for Bay of Fundy Strata (482-495) and western Scotian Shelf Strata (470-481) and then combined to generate the indices of abundance for the entire 4X5Y management area (Strata 470-495) (Table 8). Since the early portion of the series was not re-aged, only data from 1985-2015 were used as the tuning index in VPA modelling (Figure 15). During the late 1980s, there was a period of diminished numbers at age for all ages that persisted until the early 1990s. The abundance at age increased from 1995-2002, especially for ages 1-5, and was followed by an overall improvement in age structure, with increased abundance of ages 6+ up to about 2011. The 2003, 2006, and 2010 year classes all appear to have been moderately strong, with indications that the 2013 year class (Age 2 in 2015) is the strongest in the time series. In 2015, the 2013 year class (Age 2) made up 54% the survey CAA, the 2014 year class (Age 1) represented 17%, followed by the 2012 year class (Age 3) represented 13%.

The DFO Summer RV survey mean WAA (kg) and mean LAA (cm) for 4X5Y Haddock was calculated separately for Bay of Fundy and western Scotian Shelf strata, then combined after weighting using total abundance at age for each area (Tables 9 and 10). The revised survey WAA time series for 1985-2015 is used for calculations of beginning of year biomass after applying the Rivard back-calculation method (Rivard 1980). Similar to the trends observed for the commercial fishery, the DFO Summer RV survey values for mean WAA and LAA show a decline from the early 1990s to the mid-2000s then level off or show a modest increase followed by the lowest WAA for many ages occurring in 2015 (Figure 16 and 17, Table 9 and 10). A comparison of 4X5Y Haddock mean LAA for ages 3, 5, 7 and 9 from the commercial fishery and

the DFO Summer RV survey indicates a higher mean length at Age 3 in the fishery compared to the survey, with diminishing differences as age increases (Figure 18).

An analysis of condition factor, using Fulton's K (weight/length^3) showed that condition declined in Haddock (length range: 28-55 cm) from the early 1990s to mid-2000s for both areas, then showed a modest increase to 2009 before decreasing again in recent years (Figure 19). Fulton's K has generally been at or below the long term average (1970-2016) since 1993 for both areas. The overall pattern is consistent with declining trends in WAA and LAA and is similar to what has been observed for other species on the Scotian Shelf (i.e., Silver Hake, Pollock).

ESTIMATE OF STOCK PARAMETERS AND RESULTS

Prior to running the framework population model, a Virtual Population Analysis (VPA) model with random walk in natural mortality (M) was completed, including 1985-2015 data (see Wang et al. 2017 for model details). Estimated M for the 3 younger age groups 1-3, 4-6, and 7-9 continue to be relatively stable and stayed around 0.2, and M for older ages 10+ were greater and estimated as about 0.27 in the early years (1985-1990), then increased since 2000 and reached a higher level of 0.8 in most recent years (Figure 20). Natural mortality (M) for the 10+ was estimated as 0.72 in 2015 and confirms that M remains high for older ages.

The adaptive framework, ADAPT (Gavaris 1988), was used for calibrating the VPA with the trends in abundance from the DFO Summer RV survey. For 4X5Y Haddock, the model data inputs were fishery CAA for ages 1-11+ (1985-2015) and DFO Summer RV Survey swept area abundance indices for ages 1-10 (1985-2015). Zero observations for abundance indices were treated as missing data. Fishing mortality on the plus group (F11+) was set up using the Fratio method in ADAPT. Mortality was fixed at 0.2 for all the ages and years except for the ages 10-11+ after 2000. Mortality was fixed at 0.3, 0.6, and 0.9 for ages 10-11+ for three time blocks (2000-2004, 2005-2009 and 2010-2015) as recommended during the framework. The abundance at Age 1 for 2016 was assigned as the most recent 10 years of geometric mean of recruitment at Age 1 (excluding the exceptional strong 2013 year class). Other model parameters included survey catchability at age for ages 1-10 and terminal year population abundance at age for ages 2-11+. All the parameters were estimated by minimization of the discrepancy between observed and predicted values of the abundance indices at age, which were assumed to be log-normally distributed. Statistical properties of the estimators were determined using conditional non-parametric bootstrapping of model residuals (Rivard and Gavaris 2003).

The model residuals (Figure 21) suggest that some of the stronger cohorts at younger ages were underestimated by the model. The Coefficient of Variation (CV) for numbers at Age 2 for the terminal year (2016) was 0.6 (Table 11). The youngest age is expected to have the highest CV due to the limited data available for that year class. The CV for the numbers at Age 3, the 2013 year class (yc), remains high 0.4 (Table 11). The CV for numbers at age for ages 4- 11+ range from 0.19 to 0.35 (Table 11). The retrospective analysis still shows some minor retrospective patterns. For the most recent years, the model tends to overestimate the biomass and underestimate F when each year of data is peeled off (Figure 22). Survey catchability starts at 0.5 for Age 1 increases to around 1.0 at the fully recruited Age 4 with a relatively flat topped selectivity for the older ages (Table 11, Figure 23).

The calculated fishing mortality (F), the population number weighted average over ages 6-10, is shown in Figure 22 and Table 12. The model results show high fishing mortality early in the time series until about 1998, after which fishing mortality remained low. Fishing mortality (F) was estimated as 0.05 in 2015. Spawning Stock Biomass (Age 4+) decreased from 42,000 t in 1985

to 20,000 t in 1990, and started to increase in 1996 due to the contribution of the strong cohorts of 1993, 1994, 1998, 1999, and 2000; the estimated spawning stock biomass at the beginning of 2016 was 33,770 t (Figure 22 and Table 13). Preliminary estimates for the 2013 year class at Age 1 remain extraordinarily high for this stock at 264 million recruits, but as expected, it is lower than the original estimate of 317 million from the framework. The estimate for the 2014 year class (Age 1 in 2015) is 74 million, which is above the long term average for Age 1 of 31 million recruits.

STATE OF THE RESOURCE RELATIVE TO THE ADOPTED REFERENCE POINTS

Despite the uncertainties with the estimate of F_{ref} for 4X5Y Haddock, it was agreed at the framework meeting that F_{ref} when the stock is in the Healthy Zone would be 0.25, an estimated F_{msy} value from the Ricker model with a 25% probability exceeding F_{loss} based on LOESS analysis. F_{median}=0.15 from the replacement line analysis was suggested as a more appropriate target for 4X5Y Haddock in the Cautious Zone. The estimated fishing mortality in 2015 from this assessment was 0.05 for 4X5Y Haddock (Figure 22, Table 12), therefore below the F_{ref} in both Healthy Zone and Cautious Zone scenarios.

At the Framework meeting, it was agreed that $B_{recover}$ (19,700 t) would be the lower biomass reference point (B_{lim}). The estimate of the 4+ biomass in 2016 is 33,770 t for 4X5Y Haddock, above the established B_{lim} reference point (Table 13 and Figure 24).

PROJECTION AND RISK ANALYSIS

The 4X5Y Haddock age-structured fishery and survey information were updated to 2015. Beginning of terminal year (2016) population abundance was estimated from the ADAPT VPA model formulation with the value for natural mortality fixed at 0.2, except during the three time blocks of 2000-2004, 2005-2009 and 2010-2015 when M was equal to 0.3, 0.6, and 0.9 respectively for ages 10-11+. Due to many of the weights at age in 2015 being the lowest in the time series (fishery and survey, 1985-2015) the 5-year average WAA was higher than the 2015 WAA (Figure 25). Since the 5-year average would likely to lead to an overestimate of the population a more precautionary WAA, the most recent 2015 WAA, was used for both the average fishery WAA and the beginning of year population WAA. All other projection input parameters, including the 5-year average of fishery PR and the most recent 10 years of geometric mean of recruitment at Age 1 (excluding the exceptionally strong 2013 year class), remained consistent with the framework formulation (Table 14).

In the absence of an Upper Stock Reference to determine whether the stock is in the Cautious or Healthy Zone, projections were conducted using both scenarios with F_{ref}=0.25 and F=0.15. A deterministic projection was conducted with a catch of 5,100 t in 2016 under fishing at F_{ref}=0.25 in the Healthy Zone scenario for 2017 and 2018 (Table 15), and a second deterministic projection was conducted under fishing at F=0.15 in the Cautious Zone scenario for 2017 and 2018 (Table 16). In both scenarios, Spawning Stock Biomass (SSB) estimates for 2017-2019 remained above the time series average and B_{lim} (Figure 24).

The 2013 year class was estimated to contribute 61% of the population biomass projected for 2017 and 59% in 2018 (Table 15). Due to the uncertainties around the model estimate of the 2013 year class and the significant impact of that estimate on projections, sensitivity deterministic projections were conducted assuming the 2013 year class recruitment was equal to the largest recruitment in the time series prior to 2013 (54 million). Given that the 2013 year class appears to be much stronger than anything previously observed and that the 54 million falls outside of the 90% confidence interval for the estimate of the 2013 year class (104 million

to 348 million in numbers), this is a conservative approach to assessing this uncertainty. The deterministic results for this sensitivity projection are shown in Table 17 and 18. In both scenarios (F_{ref}=0.25 and F=0.15), the sensitivity projection SSB estimates for 2017-2019 remained above the time series average and B_{lim} (Figure 24).

Uncertainty about current biomass generates uncertainty in forecast results, which was expressed here as the risk of exceeding the proposed limit F_{ref}=0.25 and the recommended F while the stock is in the Cautious Zone, F=0.15, in 2017 and 2018, and the probability of adult biomass changes relative to 2018 and 2019. The risk calculations assist in evaluating the consequences of alternative catch quotas by providing a general measure of the uncertainties. However, they are dependent on the data and model assumptions and do not include uncertainty due to variations in weight-at-age, partial recruitment to the fishery, natural mortality, systematic errors in data reporting or the possibility that the model may not reflect stock dynamics closely enough, and/or retrospective bias. These projections assume that the current productivity conditions will persist over the projection period.

The stochastic projections were completed to provide the risk of F in 2017 exceeding F_{ref}=0.25 under a range of catch values, risk of F exceeding F=0.15 under a range of catch values, probability that the 2018 biomass would remain stable, and probability that biomass would not increase by 10% when compared to 2017 (Table 19 and Figure 26). Secondly, stochastic projections were completed to provide the risk of F in 2018 exceeding F_{ref}=0.25, risk of F in 2018 exceeding F=0.15 for a range of catch values, probability that the 2019 biomass would remain stable, and the probability that the 2019 biomass would not increase by 10% compared to 2018 under an F_{ref}=0.25 (Figure 27) and F=0.15 (Figure 28) in 2017 scenarios. Catch estimates ranged from 11,000 t to 27, 000 t (Table 19).

A sensitivity stochastic projection was completed to estimate the probability that the fishing mortality rate in 2018 would not exceed an F_{ref}=0.25 and F=0.15 for a range of catch values and the 2019 biomass would not increase by 10% compared to 2018 under a constant quota (5,100 t) in 2017. The results of this scenario are summarized in Figure 29.

The deterministic projections for the sensitivity analyses conducted with a value of 54 million for the 2013 year class produced catch advice for Ages 1+ of 9,666 t in 2017 and 10,379 t in 2018 with F_{ref}=0.25, and for F=0.15 produced catch advice of 5,989 t in 2017 and 6,831 t in 2018 (Table 17 and 18).

SOURCES OF UNCERTAINTY

Differences in the growth between the Bay of Fundy and the Scotian Shelf regions have been documented for this resource, and a recent analysis confirmed it is still appropriate to use separate age length keys (Stone and Hansen 2015). However, the defined survey strata used to evaluate growth differences between the Bay of Fundy and the Scotian Shelf are different from the statistical areas used to match length-weight and age length key relationships with catch data. The impact of this mismatch should be evaluated. Given that the location of future harvesting cannot be predicted, this growth mismatch could have effects on the accuracy of projections.

The Age 1+ model biomass estimate (biased adjusted) from the VPA and the survey index (not adjusted for q) were visually inspected to examine trends in the expected (VPA) and observed (survey) abundance for 2016 (Figure 30). The 1+ biomass from the VPA was used because it includes the 2013 year class (Age 3 in 2016); however, it is important to consider that abundance at Age 1 for 2016 was assigned as the most recent 10 years of geometric mean of recruitment at Age 1 (excluding the exceptional strong 2013 year class) and no error around the

Age 1 biomass was assumed. Due to the data assumptions Figure 30 was used to evaluate trends only, notably, the survey index of abundance decreased in 2016 when compared 2015, while the VPA abundance estimate suggested an increase in 2016.

The 2013 year class appears to be much stronger than anything previously observed, but there is uncertainty around this estimate given the retrospective, the small number of observations in both the survey and fishery, and the apparent mismatch between survey abundance estimates and the VPA in recent years. The CV is high for the VPA estimate of the 2013 year class (0.4 at Age 3 in 2016, Table 11). The future performance of the 2013 and 2014 year classes will impact the stock dynamics.

RESEARCH RECOMMENDATIONS

The high M used in the assessment model could be aliasing fish moving to adjacent areas or deeper waters where the fishery or survey cannot catch them. Noteworthy is that the adjacent Haddock stock on Eastern Georges Bank also shows high total mortality (Z) on older (Age 8+) fish (Stone and Hansen 2015). Research on a possible mechanism for high M on older ages would help to improve understanding of the population dynamics of 4X5Y Haddock. In addition, research on changes in growth/productivity over time and factors influencing the production of exceptionally strong year classes would also be helpful.

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TABLES

Table 1. Reported annual (January-December) and fishing year (April 1st – March 31st) catch (t) of Haddock from NAFO Division 4X, 1970-2015. Canadian landings include 5Y. CY: calendar year (January to December); FY: fishing year (January 1, 1999, to March 31, 2000, then April 1st to March 31st thereafter); TAC: total allowable catch.

Year	Catch	CY TAC	FY Catch[1]	FY TAC[1]
1970	18,072	18,000	-	-
1971	17,592	18,000	-	-
1972	13,483	9,000	-	-
1973	13,106	9,000	-	-
1974	13,378	0	-	-
1975	18,298	15,000	-	-
1976	17,498	15,000	-	-
1977	21,281	15,000	-	-
1978	27,323	21,500	-	-
1979	25,193	26,000	-	-
1980	29,210	28,000	-	-
1981	31,475	27,850	-	-
1982	25,729	32,000	-	-
1983	27,405	32,000	-	-
1984	21,156	32,000	-	-
1985	16,131	15,000	-	-
1986	15,555	15,000	-	-
1987	13,780	15,000	-	-
1988	11,272	12,400	-	-
1989	6,800	4,600	-	-
1990	7,556	4,600	-	-
1991	9,826	0	-	-
1992	10,530	0	-	-
1993	6,968	6,000	-	-
1994	4,406	4,500	-	-
1995	5,669	6,000	-	-
1996	6,245	6,500	-	-
1997	6,527	6,700	-	-
1998	7,843	8,100	-	-
1999	6,621	8,100	9,291	9,800
2000	6,961	-	7,761	8,100
2001	8,466	-	7,411	8,100
2002	7,997	-	7,930	8,100
2003	8,706	-	8,617	8,100
2004	6,553	-	5,964	10,000
2005	5,633	-	5,142	8,000
2006	4,746	-	4,687	7,000
2007	6,876	-	6,767	7,000
2008	5,372	-	5,684	7,000
2009	5,504	-	5,831	7,000
2010	5,663	-	5,379	6,000
2011	3,733	-	4,467	6,000
2012	4,127	-	3,323	5,100
2013	3,518	-	3,393	5,100
2014	2,718	-	2,825	5,100
2015	2,747*	-	2,926*	5,100

[1] Fishing year in 1999 was extended to March 3, 2000. TAC prorated upwards. Subsequent fishing years begin on April 1st.
* Extracted October 2016

Table 2. Reported annual catch (t) of Haddock from NAFO Division 4X5Y landed in the Maritimes by gear type and tonnage class, 1970-2015. MG = mobile gear tonnage class 1-3 and 4+, LL = longline, HL = handline, GN = gillnet, TC = tonnage class.

Year	MG[1] (TC 1-3)	MG (TC 4+)	LL	HL	GN	Misc[2]	Total of Gear Categories
1970	5,519	6,503	2,961	539	88	402	16,012
1971	4,743	7,716	3,227	456	79	183	16,404
1972	2,942	4,755	4,048	498	59	268	12,570
1973	1,929	4,233	5,853	377	143	145	12,680
1974	4,113	1,628	6,211	258	166	58	12,434
1975	6,183	4,406	4,944	275	176	75	16,059
1976	4,390	6,157	4,642	714	389	46	16,338
1977	6,290	8,346	4,032	411	337	177	19,593
1978	9,588	8,099	6,072	865	573	198	25,395
1979	10,293	8,638	4,349	838	399	63	24,580
1980	13,131	7,444	5,723	1,281	797	228	28,604
1981	14,912	6,649	7,008	923	856	17	30,365
1982	11,960	3,122	6,763	875	814	31	23,565
1983	12,988	2,560	7,787	786	664	56	24,841
1984	12,081	615	6,307	492	183	4	19,682
1985	10,244	563	4,028	336	110	33	15,314
1986	9,854	209	4,875	469	88	13	15,507
1987	8,177	511	4,572	286	215	3	13,763
1988	7,269	377	3,356	126	81	23	11,233
1989	3,829	90	2,469	221	158	27	6,794
1990	3,329	110	3,391	396	278	0	7,504
1991	4,182	206	4,588	539	257	1	9,772
1992	3,469	258	5,587	974	215	5	10,508
1993	2,632	123	3,227	865	100	1	6,947
1994	2,081	97	1,578	600	48	2	4,405
1995	3,062	106	2,171	250	69	2	5,660
1996	3,685	151	2,053	298	50	0	6,237
1997	4,238	65	2,066	110	58	0	6,538
1998	5,155	80	2,461	141	50	0	7,887
1999	4,475	120	1,955	40	31	0	6,621
2000	4,129	105	2,670	29	28	0	6,961
2001	6,140	88	2,227	11	21	0	8,486
2002	5,630	37	2,252	55	23	0	7,997
2003	6,616	29	2,008	26	26	0	8,706
2004	5,376	0	1,140	15	22	0	6,553
2005	4,611	53	950	5	13	0	5,633
2006	3,255	174	1,309	3	6	0	4,746
2007	5,240	50	1,583	0	3	0	6,876
2008	4,185	0	1,176	0	8	0	5,369
2009	4,563	0	933	0	7	0	5,504
2010	4,371	0	1,263	0	4	25	5,663
2011	2,800	22	906	0	4	0	3,733
2012	3,297	38	790	0	2	0	4,122
2013	3,048	46	412	0	2	0	3,518
2014	2,436	23	258	0	1	1	2,718
2015	2,637	0	107	0	4	0	2,747

[1] Mobile gears include all kinds of trawls (e.g. otter, midwater, shrimp) and pair Seine.
[2] Miscellaneous gears include trap, unknown gears, Dredge, Jigger, Pot, squid jig and weir.

Table 3. Reported commercial Haddock landings (t) by month and quarter from NAFO Divisions 4X and 5Y, 1985-2015 (from ZIF and MARFIS databases).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Qtr1	Qtr2	Qtr3	Qtr4	Total
1985	789	3898	626	1000	1164	2060	1599	1291	1585	1096	436	562	5313	4224	4475	2094	16106
1986	859	2913	1071	481	1109	1059	1262	1254	2652	1613	635	599	4843	2649	5168	2847	15507
1987	1168	2320	2085	594	1363	1381	961	777	1458	1057	347	253	5573	3338	3196	1657	13764
1988	2119	1523	216	637	808	1289	876	529	1697	790	231	503	3858	2734	3102	1524	11218
1989	996	1447	836	371	245	906	485	504	444	330	147	83	3279	1522	1433	560	6794
1990	1371	1262	288	293	429	597	739	640	864	408	309	305	2921	1319	2243	1022	7505
1991	1057	1361	318	241	542	942	1086	877	978	742	585	1042	2736	1725	2941	2369	9771
1992	1519	1052	366	228	606	1131	1297	1027	1127	801	529	825	2937	1965	3451	2155	10508
1993	361	924	452	316	676	897	909	1085	797	267	195	69	1737	1889	2791	531	6948
1994	404	280	139	209	278	692	838	366	421	289	220	268	823	1179	1625	777	4404
1995	539	387	518	230	314	445	697	570	572	492	256	640	1444	989	1839	1388	5660
1996	396	463	481	282	273	539	659	578	602	699	707	559	1340	1094	1839	1965	6238
1997	109	614	572	439	194	395	642	664	899	867	598	544	1295	1028	2205	2009	6537
1998	419	939	1103	650	132	354	743	654	1042	645	503	705	2461	1136	2439	1853	7889
1999	531	526	252	269	324	420	716	976	1114	587	495	412	1309	1012	2807	1494	6621
2000	644	1129	897	146	325	383	769	745	788	609	344	182	2670	853	2302	1135	6961
2001	1371	603	1496	343	413	389	606	840	942	628	545	292	3469	1145	2388	1464	8466
2002	982	670	772	568	361	599	902	936	816	578	428	388	2424	1528	2654	1394	8000
2003	809	398	1190	277	569	323	760	903	1243	898	832	503	2397	1169	2906	2233	8705
2004	340	617	1351	245	366	228	397	618	855	596	550	391	2308	838	1870	1537	6553
2005	402	577	741	191	176	178	420	823	875	636	456	157	1720	546	2118	1249	5633
2006	206	589	435	82	141	390	688	570	706	370	409	160	1230	614	1964	939	4746
2007	278	362	531	284	209	306	313	1059	1269	1384	522	359	1171	799	2641	2264	6876
2008	150	375	537	288	90	142	413	492	727	1008	835	314	1063	520	1632	2157	5372
2009	179	846	350	72	159	288	1021	488	837	672	349	243	1375	519	2346	1264	5504
2010	302	860	540	608	183	337	500	588	777	472	319	177	1702	1129	1864	968	5663
2011	235	886	290	47	122	295	230	353	369	351	310	245	1411	464	952	906	3733
2012	820	848	478	95	94	107	149	387	265	255	389	241	2145	296	801	885	4127
2013	272	267	802	115	97	130	538	436	241	268	193	158	1341	342	1216	619	3518
2014	143	504	568	237	129	67	104	147	257	179	181	202	1215	433	508	563	2718
2015	35	385	903	372	64	124	109	124	295	190	85	62	1322	559	528	338	2747

Table 4. Landings (t) of 4X5Y Haddock for mobile and fixed gear aggregated for Scotian Shelf (4Xmnop) and Bay of Fundy (4Xqrs5y) unit areas used in catch-at-age calculations for 1985-2015.

	Mobile		Fixed	
Year	4Xmnop	4Xqrs	4Xmnop	4Xqrs
1985	5876	5504	4456	259
1986	5255	4826	5308	129
1987	6152	2535	4911	165
1988	5969	1672	3384	309
1989	2796	1118	2803	134
1990	2107	1332	3879	340
1991	2366	2039	5120	266
1992	2143	1582	6107	673
1993	1390	1364	3725	467
1994	740	1438	2044	183
1995	1527	1641	2278	212
1996	1528	2308	2192	210
1997	1661	2642	2090	144
1998	2956	2279	2466	187
1999	2395	2202	1948	78
2000	2406	1828	2526	201
2001	3696	2531	2155	86
2002	2702	2966	2206	138
2003	2830	3816	1949	113
2004	3083	2293	1074	103
2005	3221	1443	873	96
2006	2240	1188	1231	87
2007	4197	1093	1506	81
2008	3346	839	1136	48
2009	3994	569	906	35
2010	3965	429	1212	55
2011	2531	291	876	35
2012	2833	502	780	12
2013	2496	608	397	17
2014	1802	657	251	8
2015	1817	820	105	6

Table 5. Commercial fishery Catch-at-Age (000's) for 4X5Y Haddock, 1970-2015. Separate length-weight relationships and age length keys were applied to landings and catch at size for unit areas 4Xmnop and 4Xqrs5Y. Ages 1-14 from 1985-2015 was used for assessment modelling.

	Age																
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**% of 11+**
1970	0	1088	747	1549	391	541	4679	1922	137	99	181	28	38	0	0	0	2%
1971	0	809	1660	809	1460	415	71	3404	1047	167	186	150	108	0	0	0	4%
1972	42	22	3490	1871	517	656	91	58	1185	520	26	196	93	0	0	0	4%
1973	152	3114	114	2274	1080	533	607	326	262	621	56	13	6	0	0	0	1%
1974	1	713	4783	318	1829	523	194	277	191	277	567	25	4	0	0	0	6%
1975	37	2198	4617	5220	490	1115	250	174	63	32	167	231	11	0	0	0	3%
1976	18	1306	1657	4295	3712	437	813	155	72	96	39	104	158	0	0	0	2%
1977	2	1289	3137	2026	3204	2891	361	390	107	72	23	8	87	0	0	0	1%
1978	0	77	3453	7221	2156	2916	1071	141	110	27	9	6	49	0	0	0	0%
1979	0	83	1184	6862	3970	1094	1272	269	58	70	11	1	18	0	0	0	0%
1980	16	164	2497	3071	5527	3573	538	636	173	35	21	3	10	0	0	0	0%
1981	1	1210	2268	6369	4300	3272	1191	366	331	99	14	24	9	0	0	0	0%
1982	0	526	3895	2648	4954	1823	1560	364	196	101	48	17	15	0	0	0	0%
1983	0	70	3621	6020	4104	2454	1033	434	206	131	76	27	27	0	0	0	1%
1984	2	763	1195	5046	3708	2583	1022	367	119	83	39	22	13	0	0	0	0%
1985	3	769	3778	1285	3844	1419	684	472	397	277	111	42	19	16	6	0	1%
1986	0	547	1466	3981	1781	2660	689	383	283	112	68	38	21	6	2	0	1%
1987	0	156	951	1256	3273	1252	2227	581	224	212	53	38	20	3	2	2	1%
1988	9	172	468	933	905	1839	841	947	421	245	161	56	39	23	8	4	4%
1989	0	118	461	457	825	358	836	433	476	222	80	65	33	14	4	0	4%
1990	0	314	1280	385	373	550	424	734	307	229	84	51	10	10	3	1	3%
1991	1	45	1053	2509	644	356	380	278	339	291	129	149	62	16	4	6	6%
1992	30	199	261	2699	2358	214	241	351	236	234	130	158	31	8	2	0	5%
1993	0	135	741	566	1814	1143	192	98	74	48	60	48	12	8	1	0	3%
1994	8	154	448	689	302	950	255	21	13	14	19	14	5	0	0	1	1%
1995	1	56	835	836	659	295	534	371	144	24	26	18	10	11	4	2	2%
1996	0	29	990	1084	672	428	350	467	377	130	15	1	2	1	1	3	1%
1997	0	19	578	1810	1049	457	268	146	117	108	36	8	1	0	0	1	1%
1998	0	43	143	1153	1841	1203	592	380	174	169	114	34	2	5	5	1	3%
1999	0	38	464	563	1237	942	598	230	55	49	54	25	5	0	0	0	2%
2000	0	253	456	836	561	1328	930	558	223	114	36	8	11	7	5	0	1%
2001	0	100	1654	1053	776	646	1326	923	379	124	25	16	4	15	0	0	1%
2002	1	43	511	2557	710	489	494	737	527	232	111	42	7	0	0	0	2%
2003	0	25	710	1530	2889	648	366	280	249	133	51	21	11	0	0	0	1%
2004	0	12	247	940	1207	1818	601	290	229	162	64	43	20	6	0	0	2%

	Age																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	% of 11+
2005	1	36	70	493	1509	1166	965	335	111	90	76	29	1	0	0	9	2%
2006	0	36	806	256	702	1000	868	585	193	27	50	12	10	4	0	0	2%
2007	0	206	421	3855	296	462	792	563	391	142	39	16	5	1	0	0	1%
2008	0	96	328	597	2179	352	382	689	434	261	90	33	35	1	0	0	3%
2009	4	31	372	505	589	1772	418	256	406	238	169	34	9	4	0	0	5%
2010	0	14	73	585	541	734	1837	369	170	347	161	106	17	18	0	0	6%
2011	3	68	85	284	877	422	625	794	176	73	31	30	38	5	0	0	3%
2012	8	289	307	279	272	1016	410	569	702	200	56	90	32	10	17	0	5%
2013	35	315	1721	512	240	194	468	320	140	288	106	16	21	8	3	0	4%
2014	3	314	724	1422	325	123	120	159	112	35	35	8	1	2	0	1	1%
2015	0	362	870	1010	1196	124	49	53	72	21	3	21	0	1	0	0	1%

Table 6. Commercial fishery mean weight-at-age (kg) for 4X5Y Haddock, ages 1-16, 1970-2015. Cells with dashes have no data available. Ages 1-11 WAA data from 1985-2015 is used for assessment modelling. See Fishery Catch-at-Age and Length/Weight-a-Age section for WAA calculation details.

	Age															
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1970	0.290	0.570	0.900	1.050	1.160	1.430	1.650	1.950	2.300	2.820	2.800	2.850	3.600	-	-	-
1971	0.290	0.500	0.960	1.250	1.400	1.500	1.750	1.950	2.300	2.650	3.250	3.000	3.000	-	-	-
1972	0.290	0.450	0.900	1.350	1.600	1.750	1.900	2.100	2.300	2.800	3.000	3.700	3.300	-	-	-
1973	0.270	0.510	0.750	1.250	1.800	2.000	2.200	2.300	2.500	2.700	3.300	3.400	4.200	-	-	-
1974	0.180	0.460	0.820	1.100	1.700	2.300	2.500	2.600	2.800	2.950	3.200	3.800	3.900	-	-	-
1975	0.230	0.520	0.820	1.200	1.550	2.250	2.850	3.000	3.200	3.450	3.500	3.700	4.400	-	-	-
1976	0.230	0.520	0.810	1.190	1.600	2.100	2.950	3.500	3.600	3.800	4.100	4.000	4.200	-	-	-
1977	0.280	0.460	0.710	1.220	1.720	2.200	2.940	3.300	3.570	3.770	3.690	3.940	3.910	-	-	-
1978	0.290	0.440	0.870	1.330	1.850	2.330	2.700	3.390	3.770	4.170	4.030	3.620	4.630	-	-	-
1979	0.290	0.510	0.870	1.330	1.840	2.360	2.830	3.300	4.030	4.150	4.960	6.000	5.680	-	-	-
1980	0.160	0.522	0.882	1.326	1.777	2.355	2.906	3.278	3.811	4.332	4.200	4.963	5.711	-	-	-
1981	0.230	0.593	0.877	1.260	1.721	2.219	2.654	3.134	3.608	3.688	4.546	4.823	4.680	-	-	-
1982	-	0.493	0.907	1.294	1.653	2.130	2.577	2.947	3.470	4.033	3.946	4.033	4.908	-	-	-
1983	-	0.394	0.758	1.141	1.714	2.146	2.607	2.869	3.108	3.550	3.630	3.780	4.064	-	-	-
1984	0.250	0.527	0.785	1.069	1.411	1.932	2.287	2.683	3.054	3.431	3.841	4.114	4.000	-	-	-
1985	0.300	0.624	0.841	1.025	1.243	1.506	1.860	2.003	2.085	2.195	2.585	3.034	3.268	3.259	3.359	4.125
1986	-	0.581	0.919	1.089	1.244	1.449	1.748	2.007	2.313	2.710	3.172	3.703	4.618	6.554	9.079	-
1987	-	0.694	0.840	1.073	1.191	1.377	1.573	1.872	2.116	2.365	2.716	2.607	2.307	3.570	3.765	4.527
1988	0.438	0.768	1.097	1.183	1.501	1.547	1.716	1.843	2.070	2.269	2.417	2.706	2.524	3.352	3.518	4.415
1989	-	0.703	1.105	1.286	1.419	1.531	1.694	1.725	1.823	2.005	2.363	2.391	2.490	2.785	3.064	6.008
1990	-	0.648	1.064	1.447	1.781	1.782	1.997	2.030	2.113	2.281	2.235	2.510	2.551	3.062	3.182	4.427
1991	0.492	1.053	1.006	1.364	1.684	1.948	1.983	2.038	2.104	2.107	2.208	2.198	2.360	2.579	3.355	3.190
1992	0.528	0.824	1.088	1.234	1.524	1.870	1.798	1.884	2.059	2.115	1.884	1.892	2.363	2.400	3.082	5.465
1993	-	0.733	0.933	1.092	1.352	1.695	1.994	2.077	2.267	2.216	2.296	2.057	2.347	2.620	4.297	4.668
1994	0.580	0.853	1.151	1.310	1.468	1.764	2.041	2.439	2.182	2.584	2.187	2.261	2.711	4.128	3.951	2.401
1995	0.145	0.703	1.004	1.274	1.490	1.594	1.827	1.982	2.262	2.116	2.390	2.185	2.436	2.638	2.945	3.038
1996	-	0.828	0.988	1.167	1.342	1.540	1.530	1.742	1.962	1.987	2.357	3.275	2.836	3.071	3.384	2.948
1997	-	0.758	0.968	1.230	1.472	1.758	1.932	1.908	2.082	2.193	2.521	2.035	2.698	4.163	0.000	3.451
1998	-	0.625	0.916	0.979	1.189	1.405	1.628	1.821	1.962	2.044	2.261	2.656	2.681	2.361	2.190	2.982
1999	-	0.916	1.136	1.380	1.373	1.597	1.928	2.162	2.075	2.091	2.600	2.418	2.118	5.496	5.090	-
2000	-	0.717	0.877	1.133	1.199	1.237	1.441	1.626	2.044	2.237	2.034	2.907	2.506	3.124	2.507	-
2001	-	0.714	0.958	1.054	1.177	1.171	1.270	1.449	1.636	2.018	2.320	2.409	2.530	1.743	3.002	-
2002	0.274	0.766	0.973	1.140	1.228	1.265	1.267	1.286	1.484	1.726	2.004	1.916	2.830	-	3.678	-
2003	-	0.856	1.008	1.106	1.318	1.326	1.335	1.405	1.330	1.671	2.041	2.194	2.218	-	-	-
2004	-	0.475	0.799	0.980	0.969	1.214	1.344	1.470	1.388	1.553	1.836	1.722	2.008	2.834	-	-

	Age															
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2005	0.181	0.583	0.675	0.808	1.055	1.129	1.325	1.375	1.646	1.652	1.595	1.773	3.129	-	-	1.147
2006	-	0.738	0.769	0.808	0.924	1.114	1.133	1.243	1.271	1.522	1.561	1.871	2.023	2.088	-	-
2007	-	0.736	0.718	0.895	0.876	0.995	1.138	1.089	1.190	1.297	1.413	1.665	1.357	2.188	-	-
2008	-	0.626	0.731	0.827	0.971	0.895	0.995	1.047	1.089	1.197	1.243	1.352	1.290	1.854	-	3.979
2009	0.484	0.612	0.697	0.937	1.060	1.192	1.284	1.352	1.285	1.316	1.322	1.487	1.302	2.177	-	0.000
2010	-	0.610	0.744	0.832	1.006	1.119	1.218	1.209	1.279	1.210	1.407	1.338	1.835	1.427	-	2.191
2011	0.222	0.626	0.731	0.772	0.910	1.065	1.061	1.270	1.372	1.368	1.508	1.465	1.284	1.624	-	4.045
2012	0.358	0.582	0.686	0.766	0.885	0.919	1.013	1.089	1.154	1.274	1.269	1.268	1.319	0.971	1.115	-
2013	0.358	0.473	0.672	0.736	0.876	0.868	0.968	0.998	1.129	1.161	1.320	1.348	1.225	1.124	1.535	-
2014	0.294	0.512	0.606	0.821	0.886	1.011	1.008	1.105	1.156	1.125	1.525	1.721	2.272	1.572	3.046	1.495
2015	0.106	0.409	0.574	0.707	0.862	0.980	1.005	0.973	1.024	1.150	1.597	1.329	2.980	1.094		

Table 7. The DFO Summer RV survey total biomass index (t) for 4X5Y Haddock calculated separately for Bay of Fundy strata (482-495), western Scotian Shelf strata (470-481) and both areas combined, 1970-2016. The average includes data from 1970-2016. A conversion factor of 1.2 has been applied to indices from 1970-1981 to account for vessel and gear changes.

	Total Biomass Index (t)		
Year	Strata 482-495 (BoF)	Strata 470-481 (Western SS)	Strata 470-495 (Combined)
1970	17,822	21,262	39,083
1971	13,963	36,963	50,925
1972	6,271	17,682	23,953
1973	10,112	21,207	31,319
1974	19,146	47,486	66,632
1975	8,985	28,773	37,758
1976	14,996	24,808	39,804
1977	31,059	200,867	231,926
1978	16,485	32,625	49,110
1979	45,566	36,244	81,810
1980	36,446	60,651	97,098
1981	46,729	33,594	80,323
1982	65,379	26,365	91,744
1983	21,164	25,852	47,016
1984	38,019	29,227	67,246
1985	24,561	50,678	75,239
1986	13,795	45,613	59,409
1987	9,685	20,011	29,696
1988	13,265	15,001	28,266
1989	8,686	12,855	21,541
1990	23,768	17,525	41,293
1991	32,407	28,573	60,981
1992	16,806	17,832	34,638
1993	5,109	7,692	12,800
1994	11,997	11,855	23,853
1995	28,661	20,681	49,342
1996	58,139	24,929	83,068
1997	19,550	25,661	45,210
1998	23,372	20,153	43,525
1999	15,475	40,958	56,433
2000	32,001	28,230	60,231
2001	23,239	62,160	85,399
2002	21,530	44,263	65,793
2003	36,754	31,176	67,929
2004	12,231	28,044	40,275
2005	10,639	32,882	43,522
2006	13,763	32,882	46,646
2007	20,511	34,316	54,827
2008	14,866	28,428	43,293
2009	11,262	49,565	60,827
2010	18,702	26,835	45,537
2011	12,901	34,961	47,862
2012	13,821	15,160	28,981
2013	12,729	23,852	36,581
2014	16,875	26,038	42,913
2015	32,237	37,586	69,823
2016	38,017	24,651	62,668
Average	**22,117**	**33,290**	**55,407**

Table 8. The DFO Summer RV survey total abundance index at age (000's) for 4X5Y Haddock calculated separately for Scotian Shelf strata (470-481) and Bay of Fundy strata (482-495) then combined, 1970-2015. A conversion factor of 1.2 has been applied to indices from 1970-1981 to account for vessel and gear changes. Abundance at age data from 1985-2015 was used for assessment modelling.

	Age													
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	% of 11+
1970	8,194	6,550	1,932	3,640	1,471	3,377	8,671	1,203	494	470	111	28	0	0%
1971	165	15,854	6,879	3,017	4,258	2,030	3,094	8,671	1,115	131	61	160	0	0%
1972	7,425	327	4,836	2,051	1,312	1,428	918	1,466	2,273	78	9	8	19	0%
1973	9,082	32,303	1,108	4,514	2,109	714	1,143	846	510	970	10	0	20	0%
1974	16,193	32,610	46,851	1,490	5,917	1,340	790	869	472	381	563	0	0	1%
1975	9,471	5,090	7,600	11,273	584	2,545	646	485	202	166	529	410	0	2%
1976	7,828	9,216	5,928	6,201	10,452	918	1,138	206	108	28	13	215	152	1%
1977	9,074	57,182	89,094	25,359	24,567	13,536	1,845	2,220	256	221	29	237	120	0%
1978	8,711	7,374	17,294	5,856	2,442	4,668	1,889	120	0	0	65	50	31	0%
1979	2,891	19,505	11,732	14,866	7,510	3,148	4,701	2,032	347	162	0	0	0	0%
1980	31,199	9,933	21,875	11,254	17,467	6,697	2,481	1,790	960	370	54	0	0	0%
1981	51,826	39,958	9,373	13,386	5,398	6,091	1,951	258	504	241	122	61	0	0%
1982	18,418	39,422	18,736	7,413	12,041	5,027	5,403	945	567	333	220	0	0	0%
1983	9,600	6,352	20,262	8,964	5,288	3,331	1,374	485	458	330	265	83	85	1%
1984	5,895	33,711	17,271	26,029	8,177	4,177	2,005	856	564	132	46	47	56	0%
1985	9,921	13,649	32,716	15,005	20,684	5,308	2,636	1,675	921	339	98	46	46	0%
1986	5,415	13,421	10,615	21,302	8,342	8,900	3,179	1,637	929	532	89	151	97	0%
1987	1,885	2,169	3,855	4,763	5,763	4,015	2,924	1,273	382	453	103	22	0	0%
1988	10,122	3,017	1,438	2,995	4,167	4,412	2,114	1,647	1,020	565	185	22	0	1%
1989	8,470	13,828	2,765	1,296	2,606	1,110	2,307	825	688	203	164	129	0	1%
1990	107	15,039	13,520	2,491	2,014	2,233	2,036	1,702	711	579	287	129	84	1%
1991	6,063	1,950	17,855	16,311	3,420	1,886	1,670	1,428	1,054	1,254	126	121	27	1%
1992	4,418	3,527	1,379	10,876	7,730	1,482	545	563	413	305	59	24	6	0%
1993	6,551	1,501	2,473	942	2,706	1,634	268	199	81	68	145	31	41	1%
1994	30,025	8,397	3,117	2,792	564	2,751	1,602	213	74	121	15	79	141	0%
1995	65,744	35,234	16,710	5,933	2,693	1,097	2,254	586	145	0	0	30	0	0%
1996	7,124	38,001	35,704	18,176	7,349	2,414	1,688	2,356	576	477	191	35	105	0%
1997	14,188	8,328	30,275	18,268	5,655	2,361	863	263	448	276	30	14	0	0%
1998	14,127	10,919	6,704	19,686	10,591	2,706	2,187	1,423	400	249	178	21	0	0%
1999	51,122	28,975	13,702	9,190	15,602	8,693	4,273	1,644	1,240	274	267	172	65	0%
2000	38,697	63,060	9,735	6,743	5,475	7,562	2,687	1,068	472	94	33	20	0	0%
2001	43,613	45,158	58,527	17,149	6,528	3,116	7,957	3,071	1,695	1,149	124	0	48	0%
2002	5,986	24,017	32,706	36,171	8,609	4,509	3,282	4,998	2,696	1,431	982	43	56	1%
2003	3,317	7,516	20,246	22,433	19,375	3,689	4,107	2,379	4,077	1,497	622	0	53	1%
2004	11,651	5,254	7,652	15,912	11,900	10,059	3,494	2,134	790	920	423	172	12	1%

	Age													
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	% of 11+
2005	3,365	21,234	5,056	7,306	12,913	12,368	7,104	3,528	1,149	1,042	512	189	0	1%
2006	9,539	5,163	21,094	7,640	4,664	10,719	6,646	9,327	2,059	1,478	884	184	7	1%
2007	14,461	15,744	7,266	25,721	3,742	4,477	9,176	5,694	3,559	859	685	127	68	1%
2008	961	19,145	8,983	6,292	16,109	2,052	2,249	4,967	3,806	2,176	1,324	96	187	2%
2009	2,007	1,899	22,183	12,096	7,070	13,719	3,186	3,262	5,835	5,463	1,457	524	0	3%
2010	5,259	3,203	1,586	12,893	6,387	6,623	9,388	4,870	2,014	1,512	1,021	581	296	3%
2011	17,701	10,722	3,564	3,584	15,157	5,174	5,715	7,258	3,030	1,263	2,133	523	670	4%
2012	10,427	16,385	8,745	1,935	2,117	4,879	2,937	2,170	2,326	1,990	145	380	140	1%
2013	25,684	20,310	23,063	6,651	910	1,900	2,943	2,758	1,147	878	440	26	37	1%
2014	16,8470	16,291	13,648	12,655	3,320	1,228	417	1,066	1,149	191	224	93	26	0%
2015	39,963	12,4322	28,993	18,284	12,636	2,088	1,481	460	958	219	302	78	22	0%

Table 9. Weighted DFO Summer RV survey mean weight-at-age (kg) of 4X5Y Haddock for ages 0-14 calculated separately for Scotian Shelf strata (470-481) and Bay of Fundy strata (482-495) then combined after weighting by total number, 1970-2015. Cells with dashes have no data available. Weight-at-age (WAA) data from 1985-2015 was used for assessment modelling.

	Age														
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1970	-	0.082	0.393	0.771	1.086	1.403	1.607	2.035	2.346	2.384	2.951	3.632	2.225	-	-
1971	-	0.102	0.250	0.761	1.098	1.435	1.617	1.717	2.180	2.590	4.073	3.516	4.738	-	-
1972	-	0.078	0.203	0.666	1.287	1.638	1.985	2.079	2.476	2.895	3.966	3.700	4.600	6.200	-
1973	-	0.096	0.297	0.511	1.343	1.815	2.362	2.396	2.452	2.685	2.886	3.600	-	4.000	-
1974	-	0.093	0.310	0.708	1.010	1.713	2.204	2.516	2.704	2.705	2.803	3.395	-	-	-
1975	-	0.104	0.369	0.759	1.271	1.800	2.317	2.828	3.013	3.251	3.169	3.314	3.326	-	-
1976	-	0.093	0.367	0.695	1.160	1.523	1.926	2.411	2.384	2.685	2.600	3.500	3.056	3.374	-
1977	-	0.103	0.463	0.838	1.258	1.771	2.009	2.870	2.973	4.021	2.972	3.500	3.531	3.631	3.693
1978	-	0.078	0.411	0.900	1.466	1.955	2.260	2.644	3.422	-	-	2.600	4.200	3.900	4.195
1979	-	0.084	0.347	0.786	1.369	1.757	2.383	2.738	3.368	4.034	3.477	-	-	-	3.600
1980	-	0.086	0.440	0.794	1.309	1.752	2.112	2.502	2.730	3.455	3.323	3.400	-	-	-
1981	-	0.093	0.401	0.861	1.193	1.852	2.294	2.747	3.098	3.302	4.102	3.811	4.000	-	-
1982	-	0.065	0.224	0.680	1.308	1.698	2.315	2.870	3.333	3.477	4.212	4.468	-	-	-
1983	-	0.067	0.250	0.560	1.103	1.586	1.886	2.383	2.665	2.818	3.176	3.146	3.690	4.366	-
1984	-	0.095	0.290	0.468	0.836	1.273	1.847	2.073	2.447	2.830	3.769	2.350	3.500	2.300	-
1985	-	0.076	0.331	0.550	0.728	1.010	1.380	2.023	1.977	1.936	2.483	2.635	3.200	3.100	3.036
1986	-	0.072	0.285	0.603	0.776	1.017	1.178	1.431	1.693	2.173	2.200	2.803	2.836	2.119	-
1987	-	0.099	0.345	0.581	0.968	1.154	1.139	1.436	1.660	2.090	1.816	2.328	6.000	-	2.870
1988	-	0.097	0.520	0.689	1.001	1.348	1.384	1.654	1.645	1.989	1.903	2.203	2.900	-	-
1989	-	0.090	0.356	0.747	0.911	1.292	1.510	1.543	1.612	1.555	1.799	2.310	1.310	-	2.400
1990	-	0.109	0.424	0.819	1.338	1.690	1.879	2.132	2.187	2.531	1.644	2.450	2.479	3.513	3.300
1991	-	0.089	0.600	0.839	1.331	1.503	2.083	2.064	2.123	2.005	1.679	3.511	2.564	3.555	3.400
1992	-	0.082	0.307	0.624	1.141	1.666	2.010	2.299	1.761	2.004	2.537	2.786	2.760	3.500	0.000
1993	-	0.098	0.366	0.770	1.109	1.394	1.777	1.941	1.859	1.396	2.226	2.191	1.995	1.682	4.540
1994	0.007	0.139	0.423	0.865	1.234	1.341	1.657	1.926	2.319	1.567	1.705	2.195	1.274	2.179	-
1995	0.005	0.063	0.353	0.829	1.157	1.436	1.536	1.793	2.197	2.648	-	-	1.510	-	-
1996	0.010	0.053	0.210	0.680	1.210	1.450	1.780	1.878	1.898	2.503	2.454	2.233	2.019	3.879	-
1997	0.005	0.114	0.231	0.428	0.793	1.187	1.392	1.648	1.902	1.895	1.535	2.045	1.358	-	-
1998	0.007	0.065	0.261	0.409	0.621	1.069	1.448	1.790	2.136	2.024	1.581	2.171	1.465	-	-
1999	0.009	0.104	0.188	0.540	0.606	0.820	0.966	1.171	1.314	1.373	1.890	1.809	1.642	1.347	3.260
2000	0.010	0.108	0.393	0.569	0.888	0.802	1.013	1.332	1.574	1.991	2.458	1.858	2.200	-	-
2001	0.007	0.087	0.235	0.542	0.642	0.925	0.933	1.040	1.211	1.424	1.143	1.644	-	1.450	3.810
2002	0.003	0.078	0.209	0.396	0.635	0.711	0.915	0.980	0.993	1.147	1.167	0.905	1.887	2.430	-
2003	0.005	0.068	0.215	0.356	0.670	1.076	1.045	1.109	1.133	1.288	1.316	1.442	-	2.802	-
2004	0.005	0.088	0.175	0.457	0.569	0.704	0.868	0.949	0.922	1.045	1.123	1.310	1.805	1.304	-

	Age														
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2005	0.002	0.080	0.236	0.408	0.608	0.661	0.771	0.941	0.991	1.143	1.095	1.126	1.204	-	1.830
2006	0.005	0.089	0.160	0.446	0.490	0.638	0.814	0.870	0.924	1.163	1.028	1.195	0.988	1.765	-
2007	0.003	0.075	0.184	0.419	0.721	0.780	0.897	0.928	1.089	1.100	1.403	1.200	2.180	1.491	-
2008	0.005	0.111	0.324	0.475	0.615	0.743	0.899	0.970	0.911	1.013	1.033	1.053	1.390	1.260	1.867
2009	0.006	0.118	0.299	0.484	0.650	0.744	1.002	0.937	0.949	1.025	1.047	1.148	1.247	-	1.382
2010	0.007	0.143	0.308	0.574	0.694	0.799	0.965	1.120	1.076	1.009	1.064	1.277	1.268	1.589	0.998
2011	0.006	0.120	0.318	0.646	0.672	0.782	0.904	0.873	1.040	1.086	0.912	1.027	1.292	1.102	1.342
2012	0.011	0.118	0.336	0.474	0.708	0.749	0.856	0.898	0.944	1.134	1.157	1.136	1.077	1.176	0.917
2013	0.007	0.146	0.300	0.507	0.651	0.782	0.866	0.829	0.881	1.038	1.284	1.075	1.108	1.882	-
2014	0.011	0.091	0.288	0.471	0.661	0.773	0.830	1.022	0.901	0.964	1.260	1.460	1.598	1.237	1.329
2015	0.007	0.083	0.239	0.410	0.553	0.698	0.768	0.711	0.770	0.880	1.082	0.881	1.116	2.446	-

Table 10. Weighted mean length-at-age (fork length, cm) for the DFO Summer RV survey of 4X5Y Haddock for ages 0-12, calculated separately for Scotian Shelf strata (470-481) and Bay of Fundy strata (482-495) then combined after weighting by total number; 1970-2015. Cells with dashes have no data available.

	Age												
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1970	-	20.98	33.83	41.05	45.70	49.86	52.02	56.20	59.57	60.54	65.10	68.17	60.50
1971	-	20.64	29.28	41.61	46.95	51.34	53.08	54.82	58.73	63.02	70.54	69.44	72.92
1972	-	19.92	26.92	39.40	48.56	52.83	55.93	56.36	60.07	63.21	69.13	68.50	76.50
1973	-	21.27	30.14	35.70	49.60	54.74	59.26	60.04	60.74	62.66	64.01	70.50	-
1974	-	21.02	31.10	40.02	45.23	54.38	59.19	61.26	63.12	62.80	63.50	67.97	-
1975	-	21.93	32.60	41.36	48.54	54.18	59.27	63.63	64.69	65.60	67.52	67.01	66.80
1976	-	20.99	32.34	40.01	48.41	53.12	58.07	62.82	61.32	65.69	66.50	72.50	66.88
1977	8.50	21.86	35.08	42.39	48.13	54.06	56.62	63.56	65.20	69.78	65.15	66.50	68.98
1978	-	18.97	33.72	43.00	50.22	54.74	57.66	61.25	66.17	-	-	62.50	68.50
1979	7.28	19.86	31.95	41.01	49.64	54.39	60.23	62.78	65.59	71.62	69.07	-	-
1980	6.50	19.95	33.26	40.81	49.27	54.81	58.11	61.49	62.99	67.17	67.52	70.50	-
1981	8.29	19.86	32.81	41.34	47.63	55.09	59.75	62.65	64.34	67.40	73.70	72.27	74.50
1982	6.50	17.90	26.86	38.79	48.80	53.50	59.50	63.90	67.65	68.90	74.56	74.86	0.00
1983	7.84	18.65	28.22	37.13	46.73	53.50	56.80	61.39	63.71	64.76	66.93	67.57	70.83
1984	8.18	20.53	29.39	34.49	42.22	49.13	55.77	58.92	61.43	65.54	69.43	70.50	72.50
1985	-	19.47	30.77	36.58	41.18	45.73	50.71	57.49	58.13	57.78	62.91	62.73	66.50
1986	6.50	19.50	30.07	38.20	41.01	45.38	48.27	51.21	54.22	59.77	60.10	64.82	65.53
1987		20.98	31.90	37.46	44.09	47.07	47.22	51.34	53.62	58.04	56.79	61.67	76.50
1988	6.50	20.87	34.61	40.11	44.86	49.63	49.13	51.63	52.88	54.82	54.40	59.16	62.50
1989	10.50	20.42	32.04	40.72	43.44	49.00	52.02	51.97	52.12	52.66	55.96	60.86	50.90
1990	8.50	21.53	33.12	41.64	48.80	53.84	54.66	57.25	57.69	59.82	52.33	60.67	58.09
1991	-	20.72	37.51	42.68	49.69	52.10	58.26	58.40	57.92	55.83	53.85	66.32	61.04
1992	-	19.38	30.75	39.28	47.23	53.36	57.34	59.15	54.69	55.16	61.09	64.23	62.50
1993	-	22.10	32.67	41.80	47.26	51.47	55.95	57.41	56.64	51.03	58.03	58.29	56.50
1994	8.69	23.82	34.23	42.67	48.89	49.86	53.23	56.02	60.43	53.29	54.50	58.50	51.48
1995	7.46	18.63	32.64	42.85	48.60	52.49	53.65	56.34	59.68	65.65	-	-	54.50
1996	9.66	17.84	27.37	39.94	48.62	51.66	54.77	56.82	57.55	62.51	60.51	58.50	59.55
1997	8.38	22.11	28.10	34.21	42.06	48.35	50.32	53.96	57.86	56.45	53.97	60.35	62.50
1998	8.72	18.68	29.48	34.18	38.86	46.72	51.68	54.64	58.38	56.40	54.53	60.40	54.50
1999	9.74	21.67	25.81	37.10	38.60	42.48	45.09	47.65	49.82	50.00	55.25	55.59	55.08
2000	10.01	22.33	33.68	37.86	43.78	42.72	45.59	49.95	52.00	56.36	61.52	56.50	62.50
2001	9.03	20.57	28.66	37.24	39.45	45.11	45.39	46.68	49.10	51.63	46.88	53.86	-
2002	6.50	19.93	27.59	33.97	39.76	41.41	45.54	46.54	46.57	48.87	49.06	41.64	59.60
2003	7.84	18.85	27.46	32.31	39.92	46.95	46.82	48.11	48.88	50.45	50.76	53.57	-
2004	8.51	21.57	25.94	35.92	38.39	41.28	44.01	45.81	45.46	46.89	48.58	51.11	58.28
2005	4.88	20.40	28.55	33.68	39.11	39.98	41.85	45.16	45.80	48.76	46.77	47.66	48.52
2006	8.27	21.08	26.42	35.18	36.67	40.39	43.04	43.91	45.07	48.51	46.80	49.64	47.63
2007	6.81	19.69	25.65	34.47	40.73	42.12	43.74	44.60	46.61	47.07	51.62	48.99	59.32
2008	7.96	22.02	31.83	36.45	39.02	41.68	44.23	46.01	44.53	45.83	46.08	46.98	52.30
2009	8.93	22.70	30.78	36.03	39.75	41.00	45.32	44.68	44.67	45.45	45.39	48.41	48.53
2010	9.33	24.99	31.53	37.78	41.42	43.41	45.86	48.23	47.45	46.82	47.05	50.15	50.64
2011	8.56	23.21	31.94	40.12	41.51	43.23	45.08	44.61	47.10	47.62	44.75	46.43	51.60
2012	10.61	22.99	31.85	36.70	41.56	42.48	44.70	45.47	45.82	48.81	48.70	51.50	49.82
2013	9.07	24.43	30.77	36.87	40.09	42.50	44.67	43.91	44.69	47.73	50.39	48.08	50.50
2014	10.24	20.92	30.24	36.11	40.33	42.55	43.32	47.31	45.34	45.49	50.06	52.13	53.73
2015	8.89	20.29	28.55	34.48	38.76	41.33	42.90	42.51	43.21	45.74	47.97	44.25	49.79

Table 11. ADAPT diagnostics [standard error (SE), coefficient of variation (CV), and Percent Bias (Bais %)] for the terminal year, 2016, biased population estimate (number) and catchability (q) at age. Approximate statistics assuming linearity near solution.

Mean Square Residual: 0.319				
Age	**N Estimate**	**SE**	**CV**	**Bias %**
2	73,007	46,000	0.630	15.12
3	191,730	76,166	0.397	6.77
4	23,484	8,229	0.350	5.16
5	11,828	3,450	0.292	4.34
6	9,536	3,032	0.318	3.46
7	2,814	754	0.268	1.77
8	777	225	0.289	3.72
9	357	117	0.327	3.97
10	1,584	424	0.268	2.21
11	498	94	0.188	1.56

Age	**q Estimate**	**SE**
1	0.495	0.055
2	0.769	0.081
3	0.910	0.094
4	1.089	0.110
5	1.038	0.106
6	1.004	0.103
7	1.073	0.112
8	1.100	0.122
9	1.006	0.110
10	1.080	0.116

Table 12. Estimated fishing mortality (F) from the VPA model formulation of M fixed at 0.2, except at 0.3, 0.6, and 0.9 for ages 10-11+ for the 3 time blocks (2000-2004, 2005-2009, and 2010-2015, respectively) for 4X5Y Haddock.

	Age											
Year	1	2	3	4	5	6	7	8	9	10	11	F6-10
1985	0.00	0.08	0.18	0.13	0.29	0.33	0.34	0.32	0.76	0.82	1.63	0.39
1986	0.00	0.07	0.20	0.28	0.26	0.34	0.27	0.32	0.33	0.50	1.00	0.33
1987	0.00	0.04	0.15	0.27	0.40	0.30	0.53	0.38	0.32	0.44	0.88	0.41
1988	0.00	0.03	0.16	0.22	0.32	0.41	0.33	0.45	0.53	0.68	1.37	0.42
1989	0.00	0.01	0.11	0.23	0.31	0.20	0.33	0.28	0.43	0.59	1.18	0.32
1990	0.00	0.02	0.09	0.13	0.29	0.35	0.38	0.54	0.34	0.38	0.77	0.41
1991	0.00	0.01	0.08	0.27	0.32	0.50	0.45	0.46	0.52	0.61	1.23	0.50
1992	0.00	0.02	0.06	0.32	0.43	0.17	0.75	0.98	0.93	0.83	1.67	0.57
1993	0.00	0.01	0.12	0.19	0.38	0.39	0.22	0.81	0.57	0.49	0.99	0.38
1994	0.00	0.01	0.05	0.15	0.14	0.34	0.14	0.03	0.24	0.20	0.40	0.24
1995	0.00	0.00	0.06	0.13	0.21	0.20	0.33	0.31	0.33	0.90	0.90	0.29
1996	0.00	0.00	0.05	0.11	0.15	0.20	0.40	0.54	0.59	0.57	0.57	0.38
1997	0.00	0.00	0.03	0.13	0.15	0.14	0.19	0.29	0.25	0.33	0.33	0.19
1998	0.00	0.00	0.01	0.08	0.19	0.25	0.28	0.45	0.65	0.69	0.69	0.31
1999	0.00	0.00	0.06	0.06	0.12	0.14	0.19	0.17	0.11	0.38	0.38	0.16
2000	0.00	0.01	0.02	0.14	0.08	0.18	0.20	0.27	0.24	0.35	0.35	0.20
2001	0.00	0.00	0.05	0.07	0.19	0.12	0.27	0.31	0.30	0.21	0.21	0.23
2002	0.00	0.00	0.02	0.11	0.06	0.18	0.13	0.23	0.29	0.32	0.32	0.20
2003	0.00	0.00	0.03	0.08	0.17	0.07	0.19	0.10	0.12	0.12	0.12	0.10
2004	0.00	0.00	0.02	0.05	0.08	0.15	0.09	0.23	0.11	0.11	0.11	0.13
2005	0.00	0.00	0.01	0.05	0.10	0.11	0.11	0.07	0.13	0.07	0.07	0.10
2006	0.00	0.00	0.03	0.03	0.10	0.09	0.11	0.09	0.05	0.05	0.05	0.09
2007	0.00	0.02	0.04	0.19	0.05	0.09	0.09	0.10	0.08	0.06	0.06	0.09
2008	0.00	0.01	0.05	0.08	0.15	0.07	0.10	0.11	0.11	0.09	0.09	0.10
2009	0.00	0.01	0.03	0.10	0.11	0.18	0.11	0.09	0.09	0.09	0.09	0.13
2010	0.00	0.00	0.03	0.06	0.15	0.19	0.29	0.14	0.08	0.14	0.14	0.20
2011	0.00	0.01	0.03	0.14	0.13	0.16	0.25	0.19	0.09	0.06	0.06	0.17
2012	0.00	0.01	0.04	0.12	0.20	0.22	0.23	0.38	0.26	0.19	0.19	0.25
2013	0.00	0.01	0.08	0.09	0.14	0.21	0.14	0.29	0.15	0.22	0.22	0.19
2014	0.00	0.01	0.04	0.09	0.08	0.10	0.19	0.07	0.15	0.07	0.07	0.10
2015	0.00	0.00	0.03	0.07	0.10	0.04	0.05	0.11	0.04	0.05	0.05	0.05

*Table 13. Estimated population abundance-at-age and ages 4+ biomass from the VPA model formulation of M fixed at 0.2, except 0.3, 0.6, and 0.9 for ages 10-11+ for the 3 time blocks (2000-2004, 2005-2009, and 2010-2015, respectively) for 4X5Y Haddock. *The abundance at Age 1 for 2016 was an assigned value, as the most recent 10 years of geometric mean of recruitment at Age 1 (excluding the exceptional strong 2013 year class).*

	Age											
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**4+ Biomass**
1985	11,675	11,547	25,796	11,808	16,614	5,483	2,616	1,877	811	539	260	42,280
1986	5,513	9,556	8,760	17,717	8,509	10,147	3,214	1,527	1,112	310	233	40,872
1987	7,527	4,513	7,330	5,852	10,927	5,365	5,919	2,012	906	656	222	34,967
1988	23,615	6,163	3,555	5,144	3,662	6,009	3,267	2,851	1,126	541	421	28,558
1989	21,688	19,326	4,890	2,489	3,372	2,185	3,270	1,919	1,485	544	307	20,830
1990	7,137	17,756	15,716	3,588	1,626	2,019	1,467	1,926	1,182	789	322	19,273
1991	11,419	5,843	14,254	11,712	2,591	996	1,160	821	920	692	561	26,557
1992	14,553	9,348	4,743	10,721	7,333	1,542	496	608	422	449	436	29,301
1993	22,515	11,888	7,474	3,647	6,352	3,889	1,071	191	186	136	221	21,340
1994	31,531	18,434	9,611	5,451	2,476	3,572	2,157	704	69	86	135	19,762
1995	30,880	25,808	14,953	7,465	3,842	1,755	2,072	1,536	557	45	132	23,534
1996	19,597	25,282	21,079	11,489	5,358	2,552	1,172	1,217	924	327	59	29,894
1997	13,438	16,044	20,673	16,365	8,429	3,781	1,704	645	578	419	179	33,919
1998	31,735	11,002	13,119	16,404	11,766	5,956	2,684	1,154	397	368	351	35,554
1999	53,755	25,982	8,969	10,612	12,390	7,975	3,794	1,665	604	170	295	31,597
2000	40,831	44,011	21,238	6,924	8,180	9,029	5,681	2,568	1,156	445	261	31,843
2001	42,022	33,429	35,804	16,976	4,915	6,191	6,196	3,814	1,600	745	369	35,513
2002	19,115	34,405	27,279	27,821	12,949	3,325	4,486	3,880	2,293	969	667	41,054
2003	16,676	15,650	28,129	21,873	20,472	9,961	2,282	3,228	2,514	1,404	879	48,252
2004	46,487	13,653	12,791	22,389	16,528	14,159	7,571	1,539	2,390	1,833	1,507	51,126
2005	15,811	38,060	11,167	10,249	17,482	12,444	9,954	5,656	999	1,750	2,222	45,248
2006	11,507	12,945	31,129	9,080	7,946	12,953	9,136	7,279	4,328	717	2,031	40,501
2007	19,229	9,421	10,566	24,759	7,203	5,873	9,703	6,697	5,432	3,370	1,433	49,376
2008	4,379	15,744	7,527	8,270	16,799	5,630	4,391	7,230	4,976	4,095	2,488	44,707
2009	4,906	3,585	12,803	5,867	6,232	11,791	4,292	3,251	5,298	3,637	3,308	37,225
2010	11,790	4,014	2,907	10,146	4,348	4,572	8,058	3,137	2,431	3,971	3,481	35,314
2011	34,494	9,653	3,274	2,315	7,779	3,072	3,082	4,946	2,236	1,837	2,633	25,048

Year	Age 1	2	3	4	5	6	7	8	9	10	11	4+ Biomass
2012	28,334	28,238	7,842	2,604	1,639	5,578	2,136	1,961	3,335	1,671	1,708	18,536
2013	42,148	23,191	22,859	6,143	1,880	1,097	3,653	1,380	1,095	2,099	1,128	14,898
2014	264,205	34,476	18,703	17,162	4,568	1,323	723	2,569	843	770	1,043	20,195
2015	74,395	216,310	27,944	14,659	12,769	3,447	972	484	1,959	589	687	21,400
2016	18,491*	60,910	176,773	22,093	11,091	9,376	2,710	752	348	1,539	490	33,770

Table 14. The most recent 5-year (2011-2015) average of natural mortality, 5-year average (2011-2015) of fishery partial recruitment, 2015 fishery weight-at-age, and the 2015 population beginning of year weight-at-age used in 2016-2019 projection and risk analysis for 4X5Y Haddock.

Inputs	Year	Age 1	2	3	4	5	6	7	8	9	10	11+
Natural Mortality	2016-2018	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.9	0.9
Fishery Partial Recruitment	2016-2018	0	0.05	0.3	0.6	0.8	0.8	1	1	0.8	0.7	0.7
Fishery Weight-at-Age	2016-2018	0.11	0.41	0.57	0.71	0.86	0.98	1.01	0.97	1.02	1.15	1.39
Population Beginning of Year Weight-at-Age	2016-2019	0.05	0.14	0.31	0.48	0.62	0.73	0.74	0.74	0.82	0.98	1.02

Table 15. Deterministic projections for 2016-2019 under a fishing the TAC (5,100) for 2016 and the fishing mortality rate of F_{ref}=0.25 for 2017-18 scenario for 4X5Y Haddock. The Age 1 of 2016-2019 year classes was fixed at the most recent 10 years of geometric mean of recruitment at Age 1 (excluding the exceptional strong 2013 year class).

Year/Age	1	2	3	4	5	6	7	8	9	10	11+	1+	4+
Fishing Mortality													
2016	0	0.005	0.028	0.057	0.076	0.076	0.095	0.095	0.076	0.066	0.066	-	-
2017	0	0.013	0.075	0.15	0.2	0.2	0.25	0.25	0.2	0.175	0.175	-	-
2018	0	0.013	0.075	0.15	0.2	0.2	0.25	0.25	0.2	0.175	0.175	-	-
Projected Population Numbers													
2016	18,491	60,910	176,773	22,093	11,091	9,376	2,710	752	348	1,539	490	-	-
2017	18,491	15,139	49,633	140,679	17,090	8,418	7,117	2,019	560	264	772	-	-
2018	18,491	15,139	12,241	37,700	99,135	11,456	5,643	4,538	1,287	375	354	-	-
2019	18,491	15,139	12,241	9,298	26,567	66,452	7,679	3,598	2,894	863	249	-	-
Projected Population Biomass													
2016	906	8,588	55,330	10,516	6,887	6,863	2,003	556	286	1,502	500	93,939	29,115
2017	906	2,135	15,535	66,963	10,613	6,162	5,259	1,494	461	258	788	110,574	91,998
2018	906	2,135	3,831	17,945	61,563	8,386	4,170	3,358	1,059	366	361	104,080	97,208
2019	906	2,135	3,831	4,426	16,498	48,643	5,675	2,663	2,381	842	254	88,253	81,381
Projected Catch Numbers													
2016	0	261	4,486	1,106	734	620	222	62	23	65	21	-	-
2017	0	170	3,255	17,805	2,817	1,388	1,433	406	92	28	83	-	-
2018	0	170	803	4,771	16,341	1,888	1,136	914	212	40	38	-	-
Projected Catch Biomass													
2016	0	107	2,557	785	631	608	224	60	23	75	29	5,100	2,436
2017	0	70	1,855	12,641	2,423	1,360	1,447	394	94	33	115	20,432	18,507
2018	0	70	458	3,388	14,054	1,851	1,147	886	216	46	53	22,168	21,641

Table 16. Deterministic projections for 2016-2019 under a fishing the TAC (5,100) for 2016 and the fishing mortality rate of F=0.15 for 2017-18 scenario for 4X5Y Haddock. The Age 1 of 2016-2019 year classes was fixed at the most recent 10 years of geometric mean of recruitment at Age 1 (excluding the exceptional strong 2013 year class).

Year/Age	1	2	3	4	5	6	7	8	9	10	11+	1+	4+
Fishing Mortality													
2016	0	0.005	0.028	0.057	0.076	0.076	0.095	0.095	0.076	0.066	0.066	-	-
2017	0	0.008	0.045	0.09	0.12	0.12	0.15	0.15	0.12	0.105	0.105	-	-
2018	0	0.008	0.045	0.09	0.12	0.12	0.15	0.15	0.12	0.105	0.105	-	-
Projected Population Numbers													
2016	18,491	60,910	176,773	22,093	11,091	9,376	2,710	752	348	1,539	490	-	-
2017	18,491	15,139	49,633	140,679	17,090	8,418	7,117	2,019	560	264	772	-	-
2018	18,491	15,139	12,302	38,848	105,265	12,410	6,113	5,015	1,422	407	379	-	-
2019	18,491	15,139	12,302	9,629	29,069	76,438	9,011	4,308	3534	1,033	288	-	-
Projected Population Biomass													
2016	906	8,588	55,330	10,516	6,887	6,863	2,003	556	286	1,502	500	93,939	29,115
2017	906	2,135	15,535	66,963	10,613	6,162	5,259	1,494	461	258	788	110,574	91,998
2018	906	2,135	3,851	18,492	65,370	9,084	4,518	3,711	1,171	397	387	110,020	103,128
2019	906	2,135	3,851	4,583	18,052	55,953	6,659	3,188	2,909	1,008	293	99,536	92,645
Projected Catch Numbers													
2016	0	261	4,486	1,106	734	620	222	62	23	65	21	-	-
2017	0	103	1,981	10,991	1,755	865	901	255	57	18	51	-	-
2018	0	103	491	3,035	10,810	1,274	774	635	146	27	25	-	-
Projected Catch Biomass													
2016	0	107	2,557	785	631	608	224	60	23	75	29	5,100	2,436
2017	0	42	1,129	7,803	1,509	847	910	248	59	20	71	12,638	11,467
2018	0	42	280	2,155	9,297	1,249	781	616	149	31	35	14,634	14,312

Table 17. A sensitivity projection run completed by adjusting the 2013 year class to 53,755 (abundance at Age 1 in 1999), the maximum recruitment in the time series (1985-2013), and F=0.25 for 4X5Y Haddock. The Age 1 of 2016-2019 year classes was fixed at the most recent 10 years of geometric mean of recruitment at Age 1 (excluding the exceptional strong 2013 year class).

Year/Age	1	2	3	4	5	6	7	8	9	10	11+	1+	4+
Fishing Mortality													
2016	0	0.008	0.05	0.1	0.134	0.134	0.167	0.167	0.134	0.117	0.117	-	-
2017	0	0.013	0.075	0.15	0.2	0.2	0.25	0.25	0.2	0.175	0.175	-	-
2018	0	0.013	0.075	0.15	0.2	0.2	0.25	0.25	0.2	0.175	0.175	-	-
Projected Population Numbers													
2016	18,491	59,046	35,704	20,818	10,791	8,949	2,590	735	328	1,476	469	-	-
2017	18,491	15,139	47,940	27,801	15,416	7,728	6,409	1,794	509	235	703	-	-
2018	18,491	15,139	12,241	36,414	19,591	10,334	5,180	4,086	1,144	341	320	-	-
2019	18,491	15,139	12,241	9,298	25,660	13,132	6,927	3,303	2,606	767	226	-	-
Projected Population Biomass													
2016	906	8,325	11,175	9,909	6,701	6,551	1,914	544	270	1,440	478	48,214	27,807
2017	906	2,135	15,005	13,233	9,573	5,657	4,736	1,327	419	229	717	53,938	35,892
2018	906	2,135	3,831	17,333	12,166	7,564	3,828	3,024	941	333	327	52,388	45,516
2019	906	2,135	3,831	4,426	15,935	9,613	5,119	2,444	2,144	748	230	47,532	40,660
Projected Catch Numbers													
2016	0	446	1,586	1,805	1,228	1,019	363	103	37	108	34	-	-
2017	0	170	3,143	3,519	2,541	1,274	1,290	361	84	25	75	-	-
2018	0	170	803	4,609	3,229	1,703	1,043	823	189	37	34	-	-
Projected Catch Biomass													
2016	0	183	904	1,282	1,056	998	366	100	38	125	48	5,100	4,013
2017	0	70	1,792	2,498	2,185	1,248	1,303	350	86	29	105	9,666	7,805
2018	0	70	458	3,272	2,777	1,669	1,053	798	192	42	48	10,379	9,852

Table 18. A sensitivity projection run completed by adjusting the 2013 year class to 53,755 (abundance at Age 1 in 1999), the maximum recruitment in the time series (1985-2013), and F=0.15 for 4X5Y Haddock. The Age 1 of 2016-2019 year classes was fixed at the most recent 10 years of geometric mean of recruitment at Age 1 (excluding the exceptional strong 2013 year class).

Year/Age	1	2	3	4	5	6	7	8	9	10	11+	1+	4+
Fishing Mortality													
2016	0	0.008	0.05	0.1	0.134	0.134	0.167	0.167	0.134	0.117	0.117	-	-
2017	0	0.008	0.045	0.09	0.12	0.12	0.15	0.15	0.12	0.105	0.105	-	-
2018	0	0.008	0.045	0.09	0.12	0.12	0.15	0.15	0.12	0.105	0.105	-	-
Projected Population Numbers													
2016	18,491	59,046	35,704	20,818	10,791	8,949	2,590	735	328	1,476	469	-	-
2017	18,491	15,139	47,940	27,801	15,416	7,728	6,409	1,794	509	235	703	-	-
2018	18,491	15,139	12,302	37,523	20,802	11,194	5,612	4,516	1,264	370	343	-	-
2019	18,491	15,139	12,302	9,629	28,077	15,106	8,129	3,955	3,182	918	261	-	-
Projected Population Biomass													
2016	906	8,325	11,175	9,909	6,701	6,551	1,914	544	270	1,440	478	48,214	27,807
2017	906	2,135	15,005	13,233	9,573	5,657	4,736	1,327	419	229	717	53,938	35,892
2018	906	2,135	3,851	17,861	12,918	8,194	4,147	3,342	1,040	361	350	55,105	48,213
2019	906	2,135	3,851	4,583	17,436	11,057	6,007	2,926	2,619	896	266	52,682	45,791
Projected Catch Numbers													
2016	0	446	1,586	1,805	1,228	1,019	363	103	37	108	34	-	-
2017	0	103	1,913	2,172	1,583	794	811	227	52	16	47	-	-
2018	0	103	491	2,931	2,136	1,150	710	572	130	24	23	-	-
Projected Catch Biomass													
2016	0	183	904	1,282	1,056	998	366	100	38	125	48	5,100	4,013
2017	0	42	1,091	1,542	1,361	778	819	220	53	18	65	5,989	4,857
2018	0	42	280	2,081	1,837	1,127	717	554	132	28	32	6,831	6,509

Table 19. The levels of catch (t) projected in 2016 for which there is a 25%, 50%, and 75% percent risk of the fishing mortality in 2017 and 2018 exceeding F_{ref}=0.25 and F=0.15.

Probability of Exceeding	Catch Year	25%	50%	75%
F=0.15	2017	11,000	12,980	15,240
F=0.25	2017	17,780	21,040	24,660
F=0.15 if F=0.15 in 2017	2018	12,600	15,100	17,600
F=0.25 if F=0.25 in 2017	2018	19,100	23,100	27,100

FIGURES

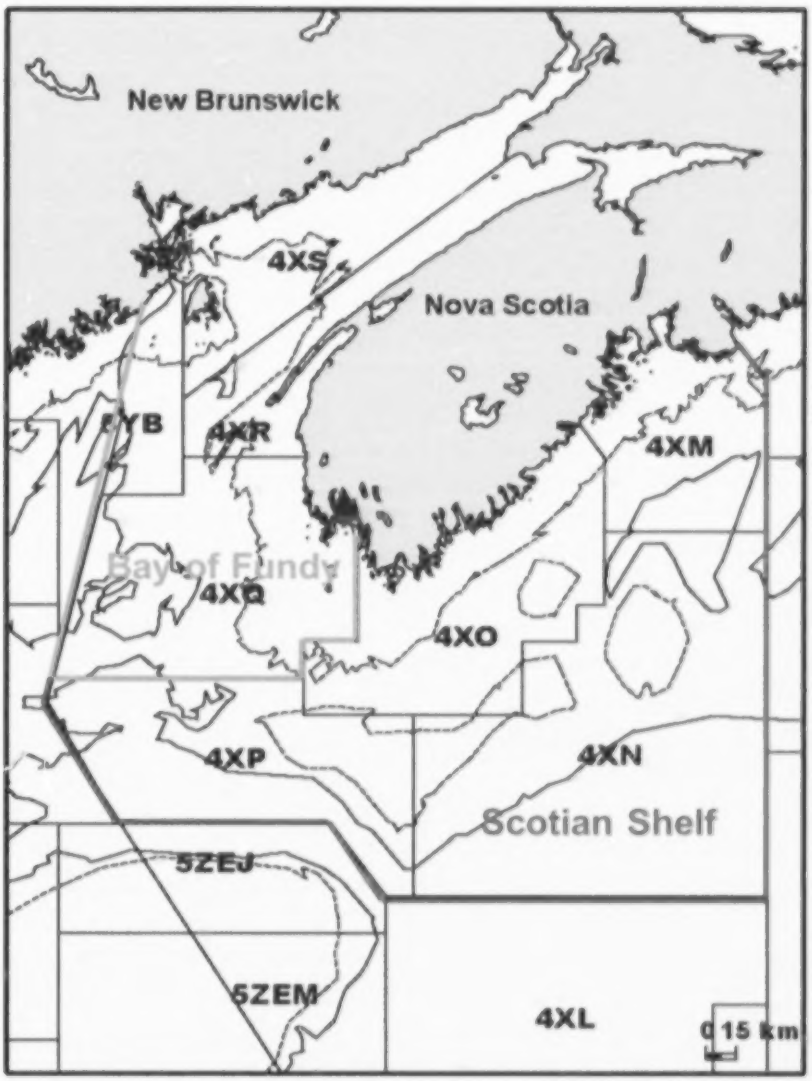


Figure 1. Map of the 4X5Y Haddock management area and Canadian Statistical unit areas for the Bay of Fundy (4Xqrs) and western Scotian Shelf (4Xmnop). Separate age length keys for the western Scotian Shelf and Bay of Fundy are used for calculating the catch at age and survey age-specific indices of abundance. Haddock landed from statistical areas 5ZEM and 5ZEJ are not included in the 4X5Y Haddock stock assessment.

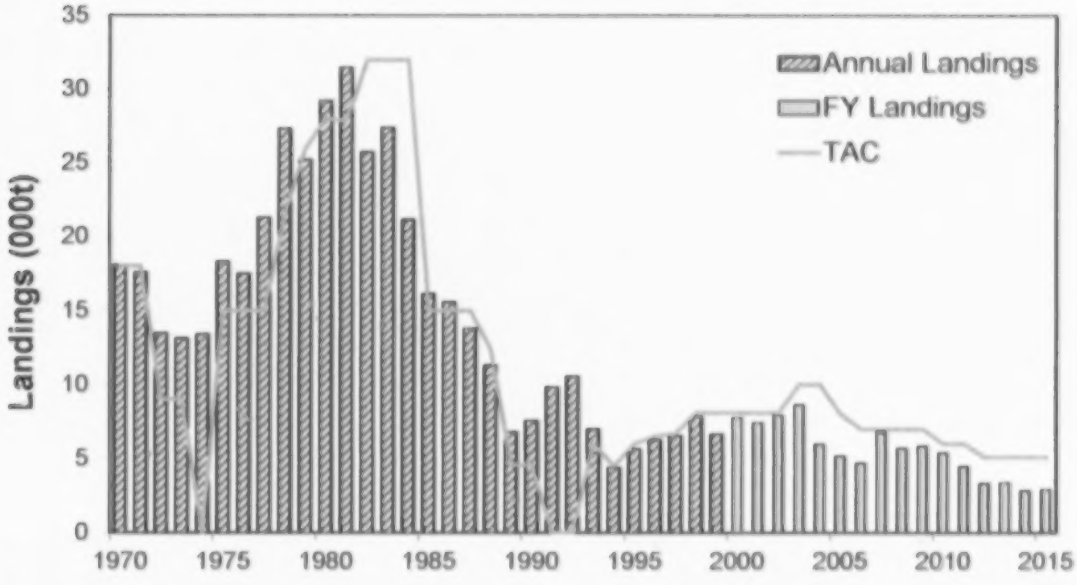


Figure 2. Reported annual landings (t), fishing year landings (FY; April 1st - March 31st) and TAC for the 4X5Y Haddock fishery, 1970-2015.

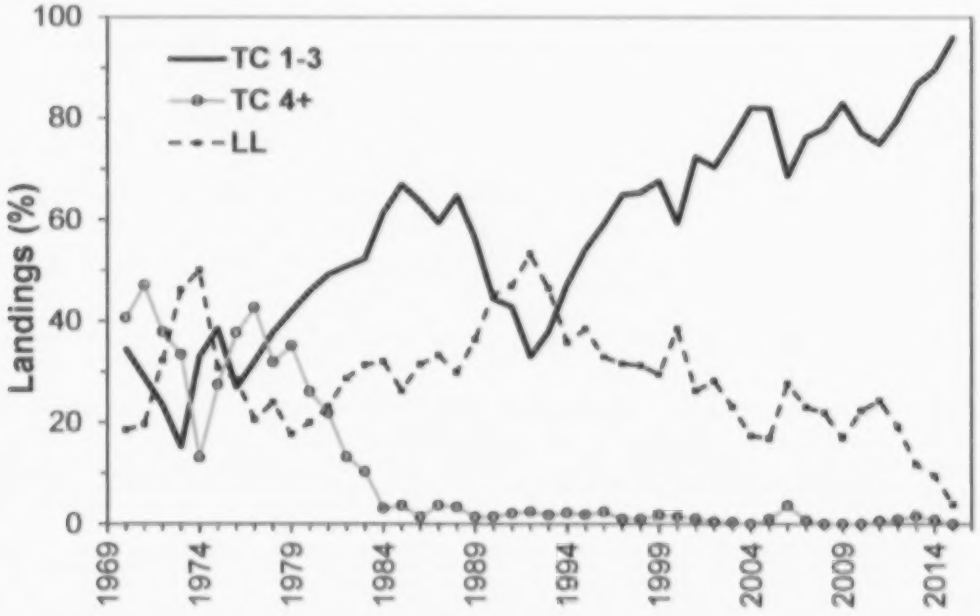


Figure 3. Percentage of annual landings (t) by gear type for the 4X5Y Haddock fishery, 1970-2015. TC 1-3 = otter trawl tonnage class 1-3; TC 4+ = otter trawl tonnage class 4+; LL = longline.

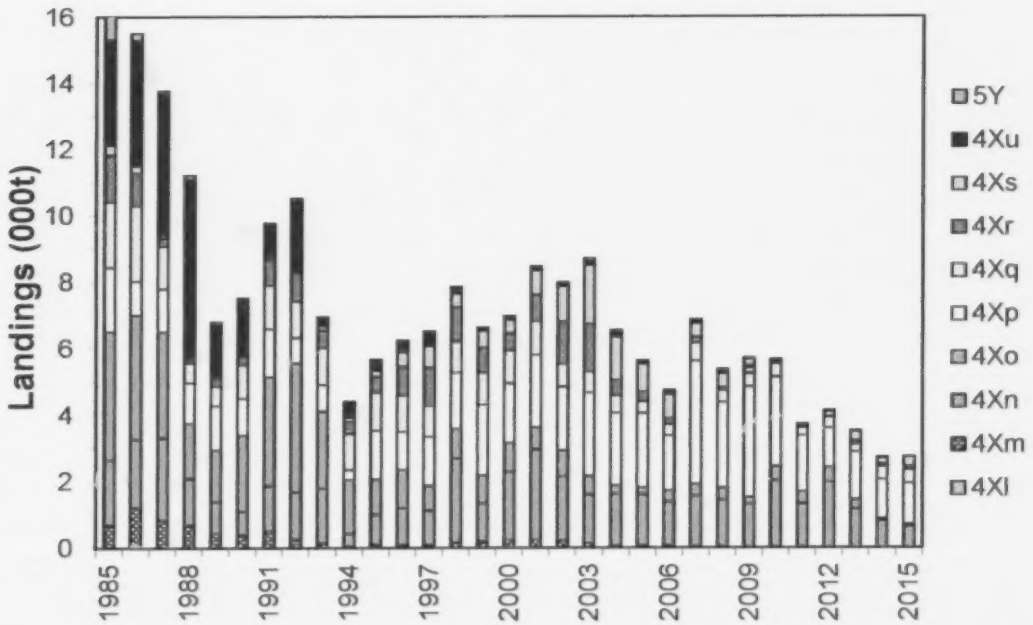


Figure 4. Annual landings (t) by Canadian statistical unit area for the 4X5Y Haddock fishery, 1985-2015.

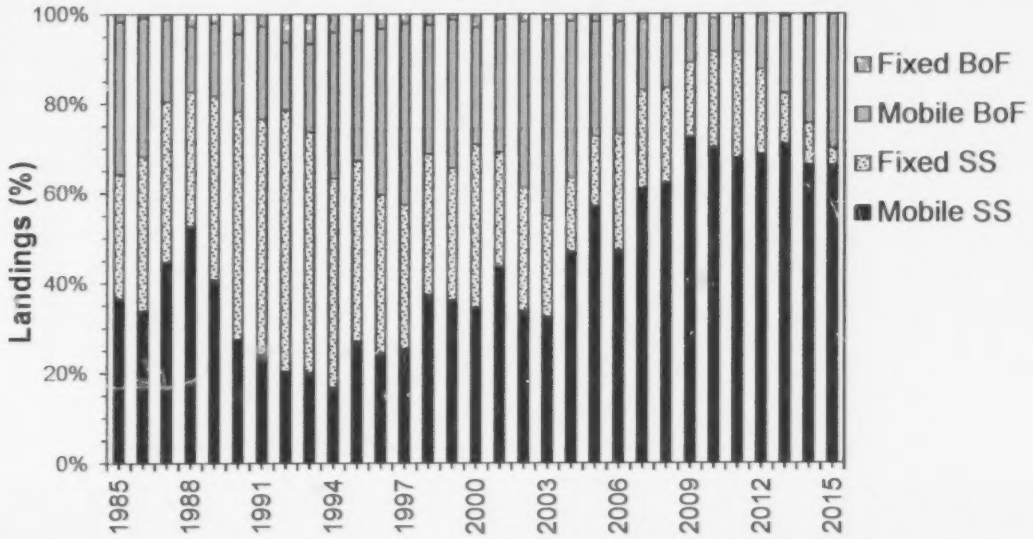


Figure 5. Annual landings (%) by gear sector for Canadian statistical unit areas representing the western Scotian Shelf (SS; 4Xmnop) and Bay of Fundy (BoF; 4Xqrs5Y) areas of the 4X5Y Haddock fishery, used in catch-at-age calculations for 1985-2015.

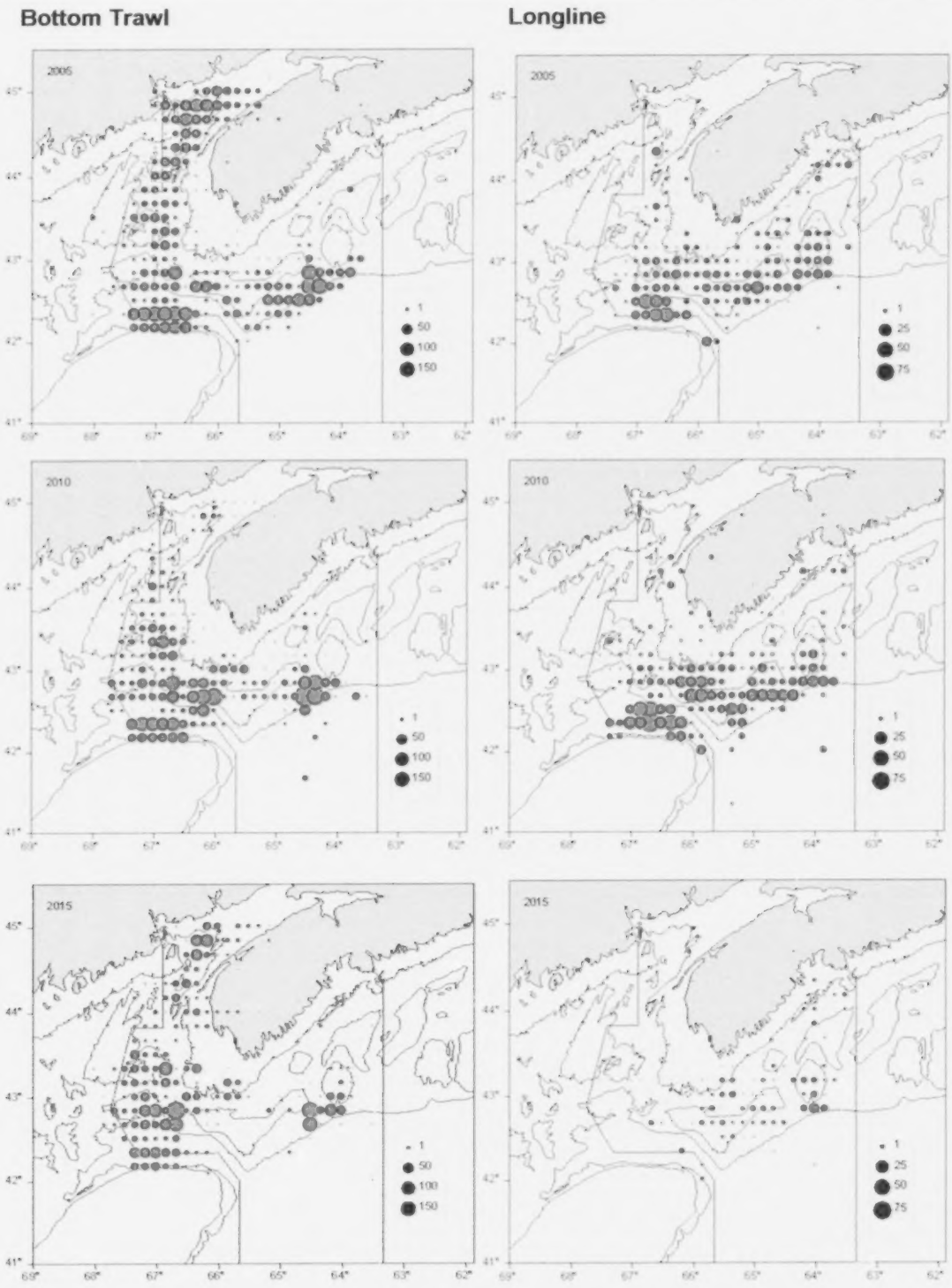


Figure 6. Distribution of 4X5Y Haddock catches (t) by gear type for 2005, 2010 and 2015.

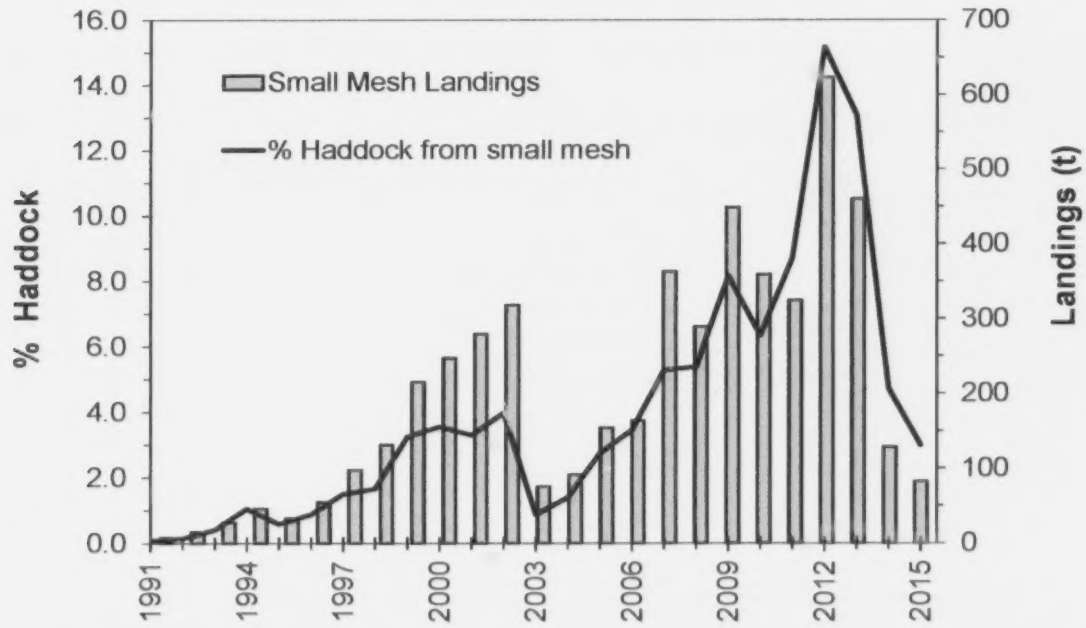


Figure 7. 4X5Y Haddock landings (t) from small mesh otter trawl (cod end mesh size:110-112 mm diamond) and % of total annual landings, 1991-2015.

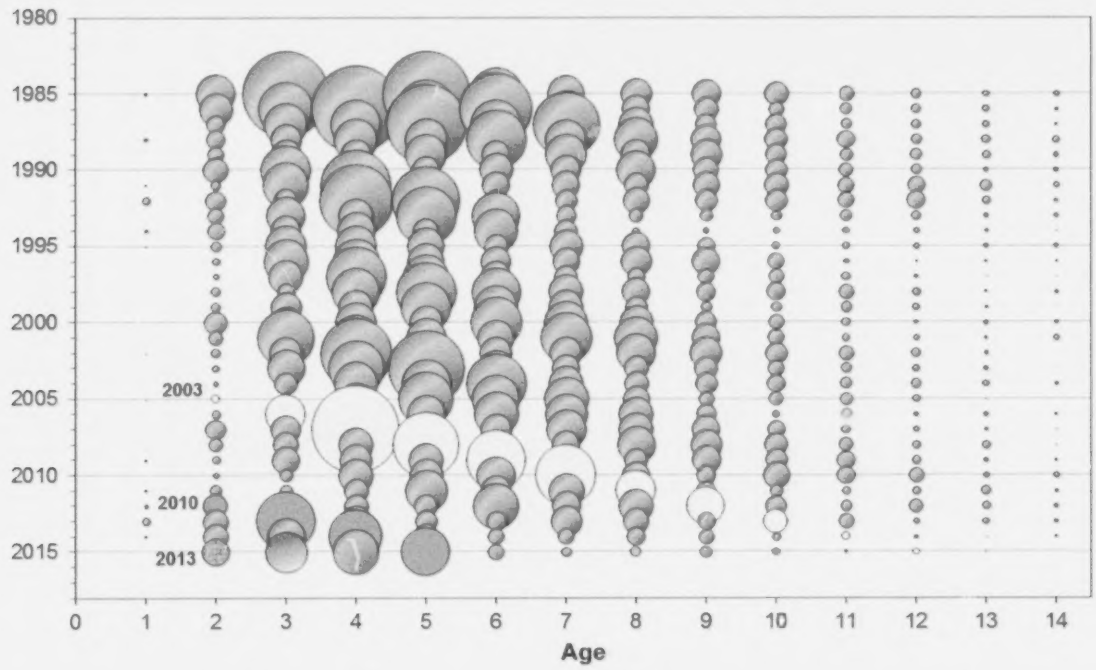


Figure 8. Catch-at-age for 4X5Y Haddock for ages 1-14, 1985-2015. The area of the circle is proportional to the catch at that age and year. Three examples of recent strong cohorts are highlighted: 2003 (yellow), 2010 (red), and 2013 (blue). Data from 1985-2015 was used for assessment modelling.

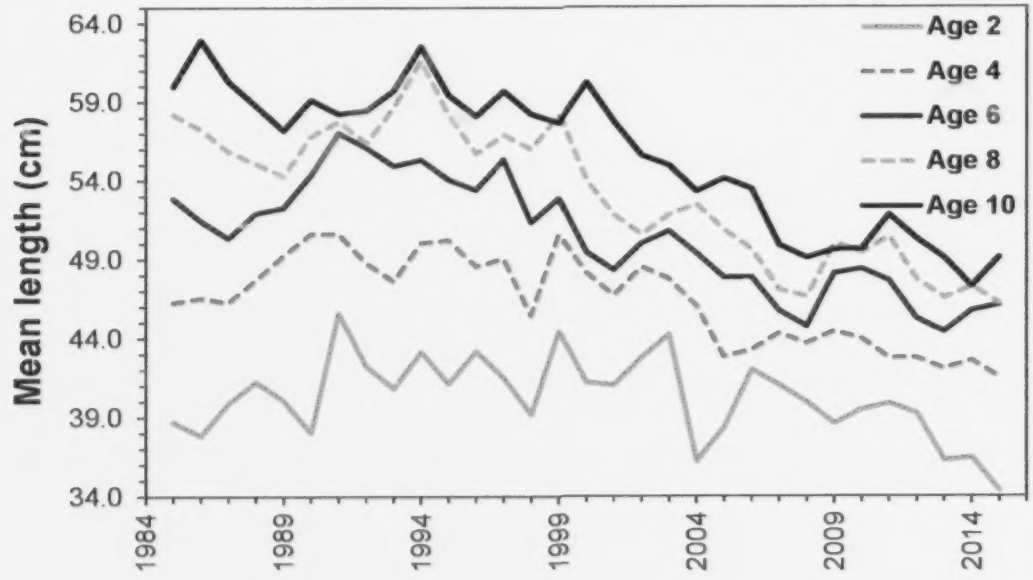


Figure 9. Commercial fishery mean weighted length-at-age (cm), calculated using the catch-at-age application (see text for details), for 4X5Y Haddock ages 2, 4, 6, 8, and 10 for 1985-2015.

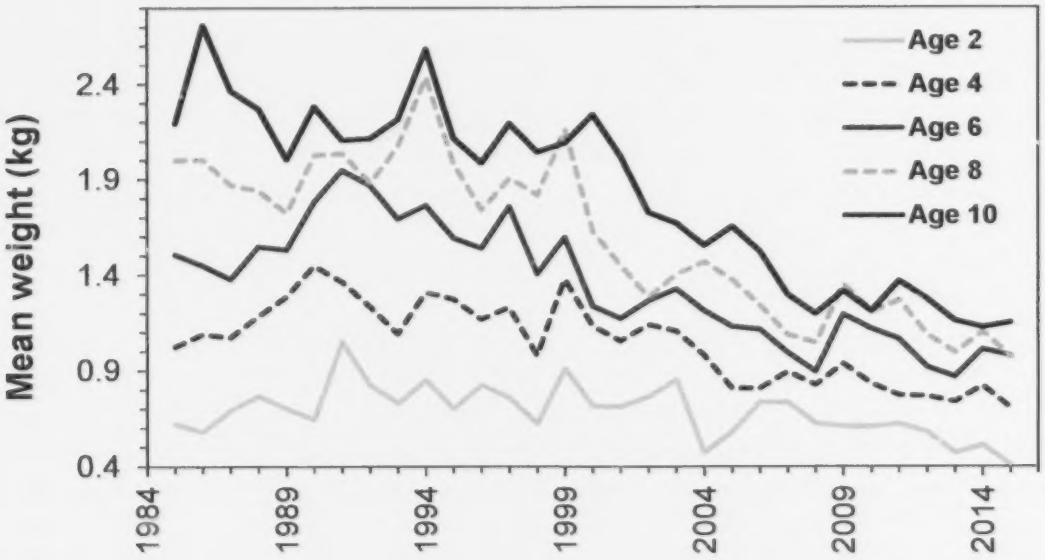


Figure 10. Commercial fishery mean weighted weight-at-age (kg), calculated using the catch-at-age application (see text for details), for 4X5Y Haddock ages 2, 4, 6, 8, and 10 for 1985-2015.

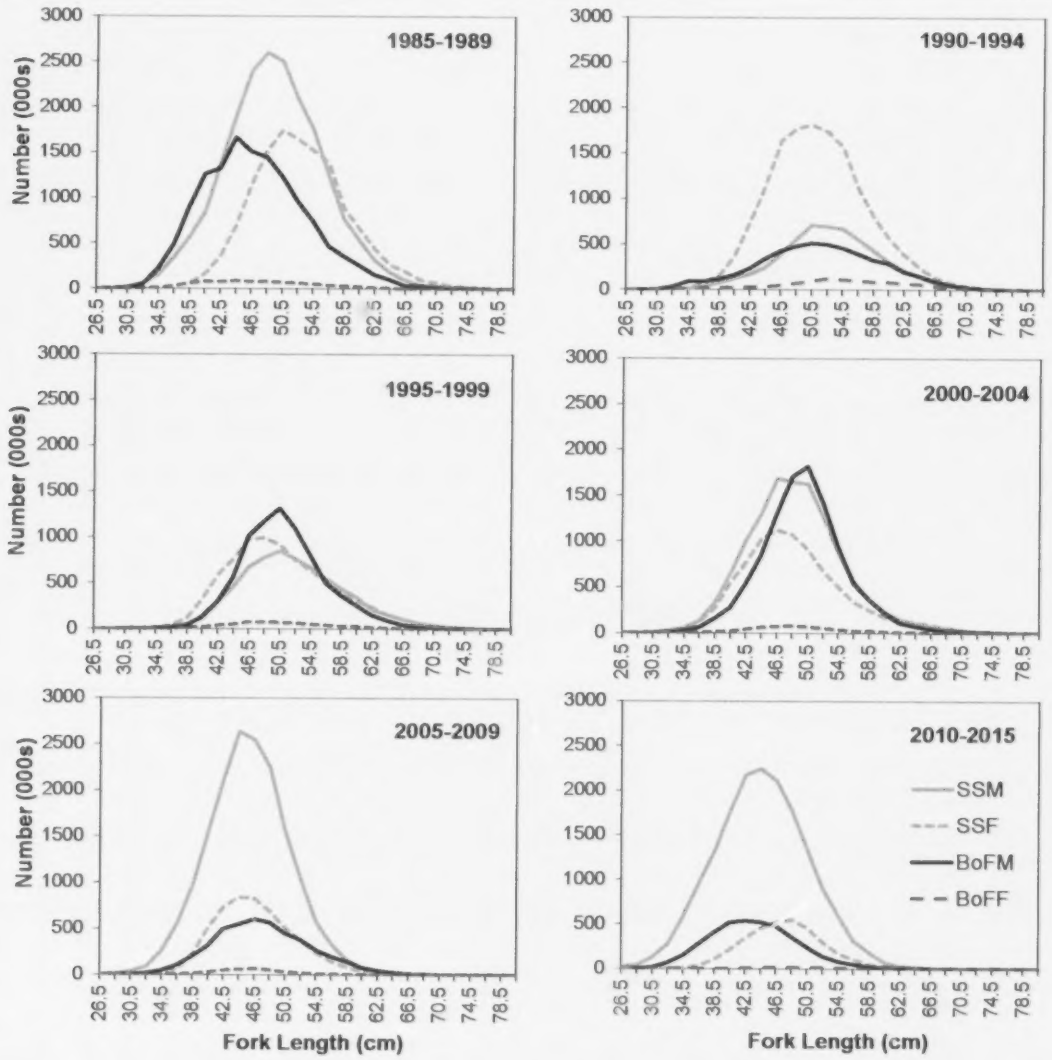


Figure 11. 4X5Y Haddock commercial fishery catch at size by area (SS: Scotian Shelf; BoF: Bay of Fundy) and gear type (M: mobile; F: fixed) summed over year intervals, 1985-2015.

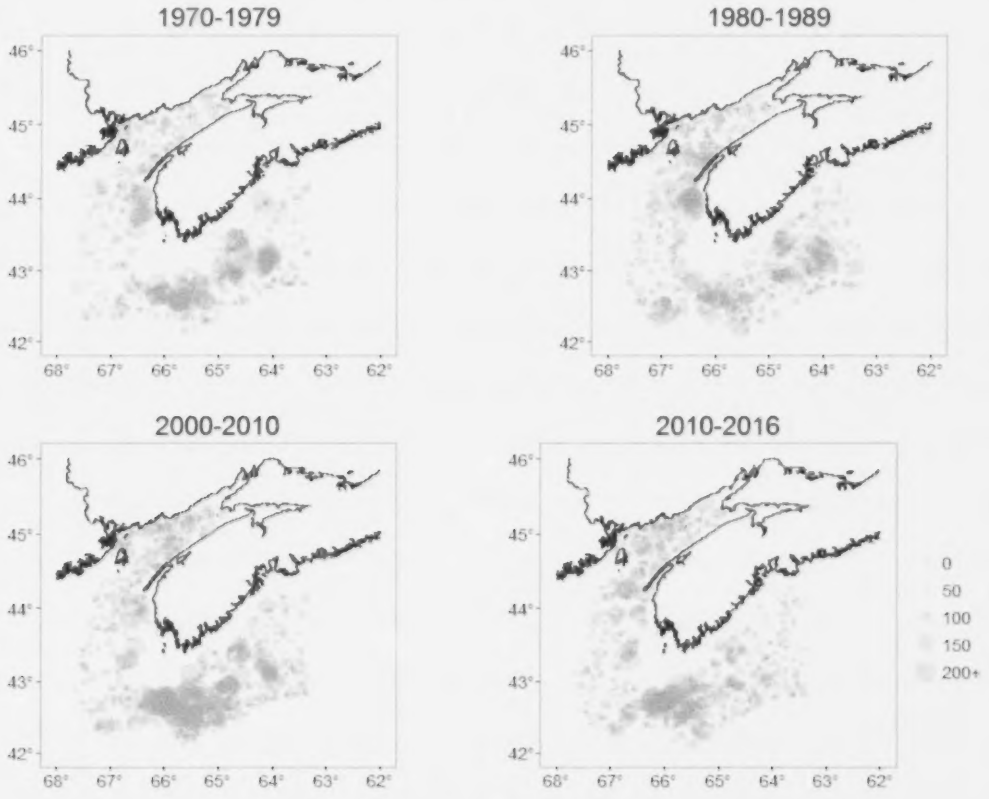


Figure 12. Distribution of 4X5Y Haddock catches (kg/tow) from the DFO Summer RV survey, a 10 or 6 (2010-2016) year average aggregated by 10 minute squares from survey Strata 470-495, 1970-2016.

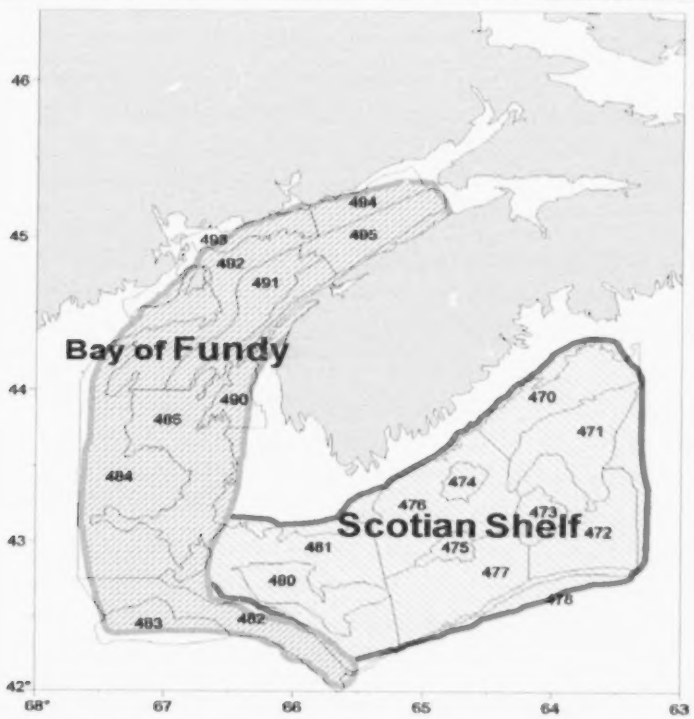


Figure 13. The DFO Summer RV survey strata and area of coverage for Scotian Shelf (Strata 470-481, blue shading) and Bay of Fundy (Strata 482-495; pink shading) areas of 4X5Y.

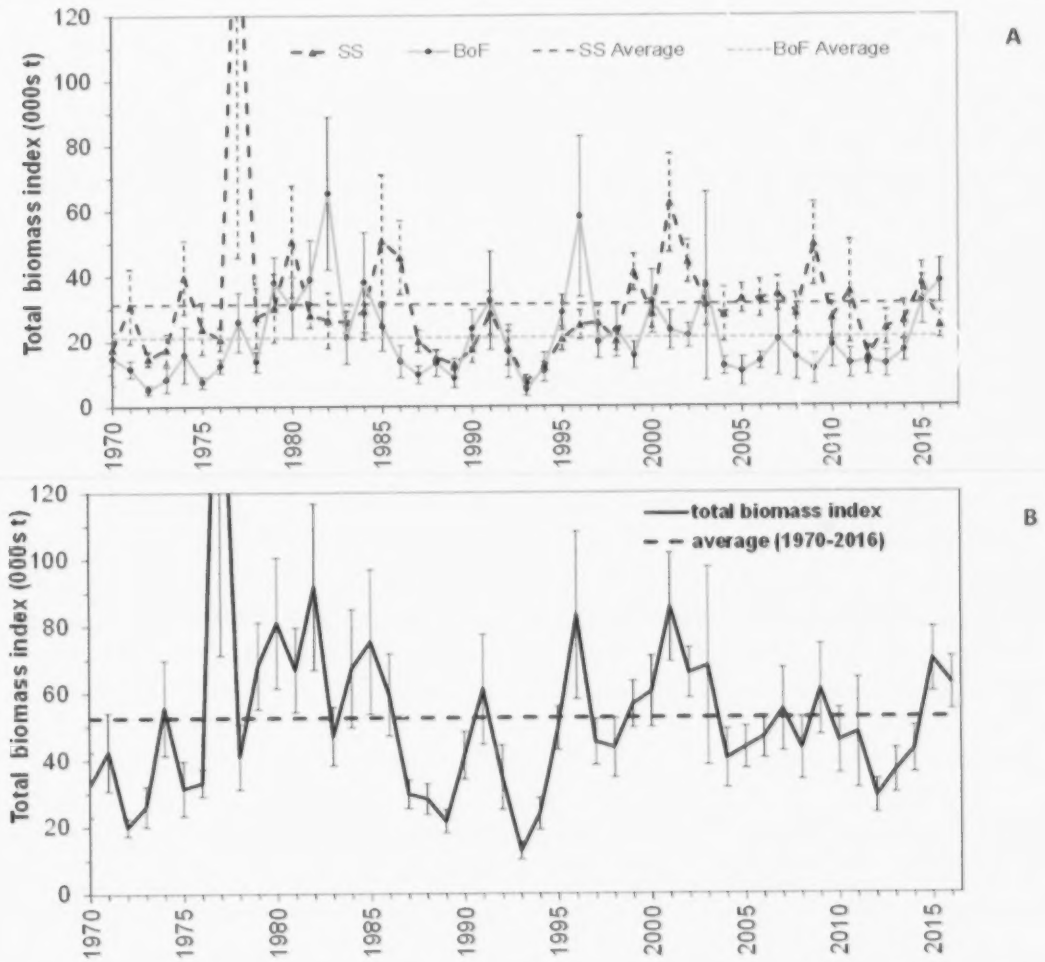


Figure 14. Trends in the total biomass index ± standard error (000 t), including all ages, from the DFO Summer RV survey for Scotian Shelf (Strata 470-481), Bay of Fundy (Strata 482-495) (A) and both areas combined (4X5Y; B) compared to the long term average for each series from 1970-2016. A conversion factor of 1.2 has been applied to total biomass estimated for 1970-1981 to account for vessel and gear changes.

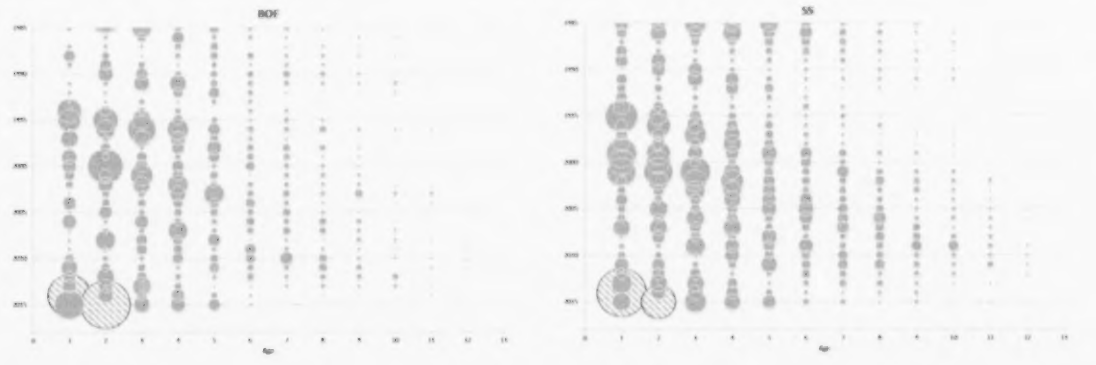


Figure 15. Stratified total number per tow at age (1-13) for 4X5Y Haddock from the DFO Summer RV survey, Bay of Fundy (BOF) and the Scotian Shelf (SS), 1985-2015. The patterned circle represents the 2013 year class at age 1 in 2014 and Age 2 in 2015. The area of the circle is proportional to the catch at that age and year. Abundance at age data from 1985-2015 was used for assessment modelling.

Figure 16. The DFO Summer RV survey mean length-at-age (cm) for the each area (Scotian Shelf and Bay of Fundy) for 4X5Y Haddock ages 3, 5, 7, and 9 for 1985-2015.

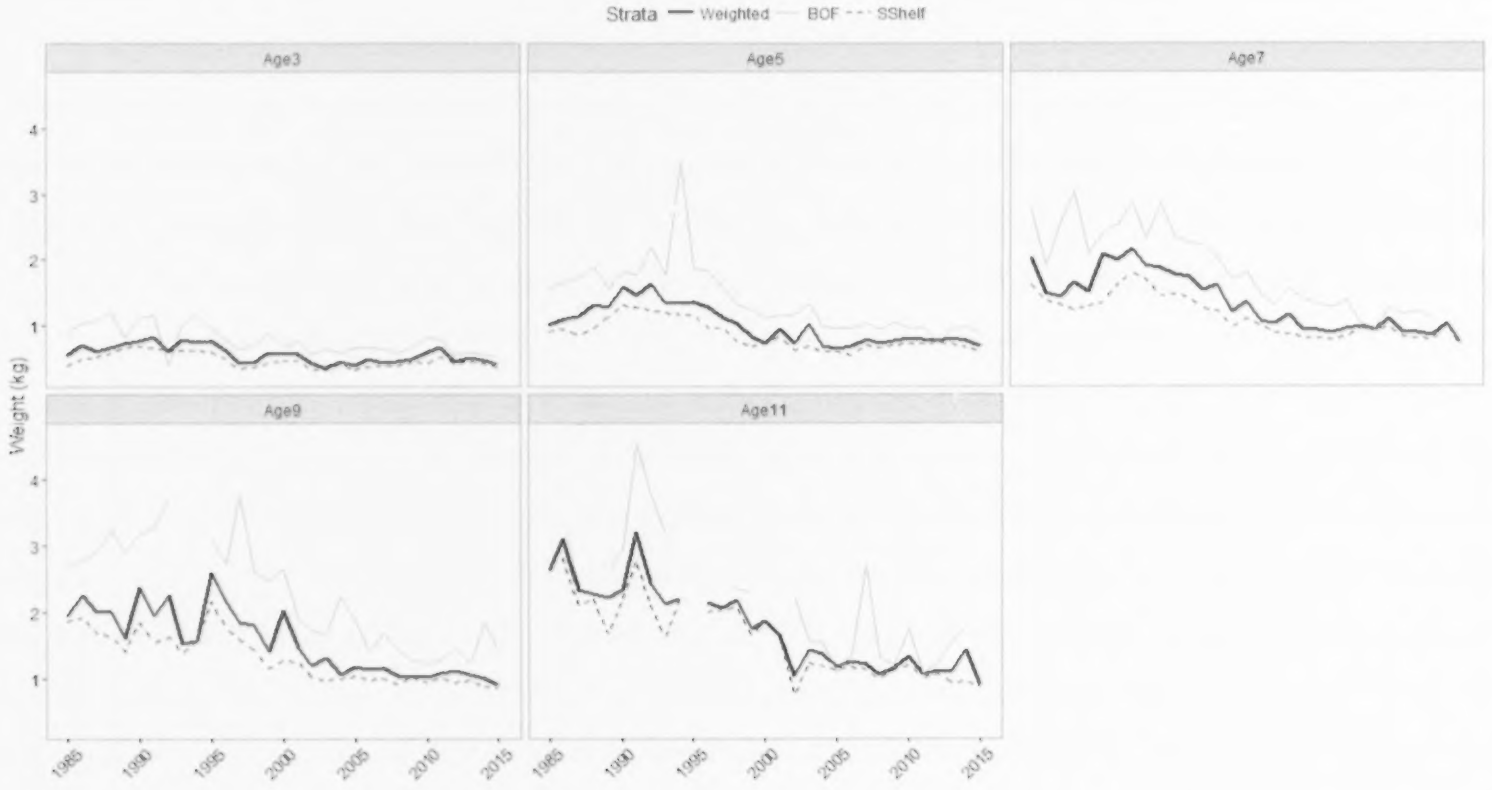


Figure 17. The DFO Summer RV survey mean weight-at-age (kg) for the each area (Scotian Shelf and Bay of Fundy); as well as the mean weighted weight-at-age (combined) for 4X5Y Haddock ages 3, 5, 7, 9, and 11 for 1985-2015. Mean weighted weights-at-age were calculated separately for Bay of Fundy and western Scotian Shelf strata then combined after weighting using total abundance at age from each area.

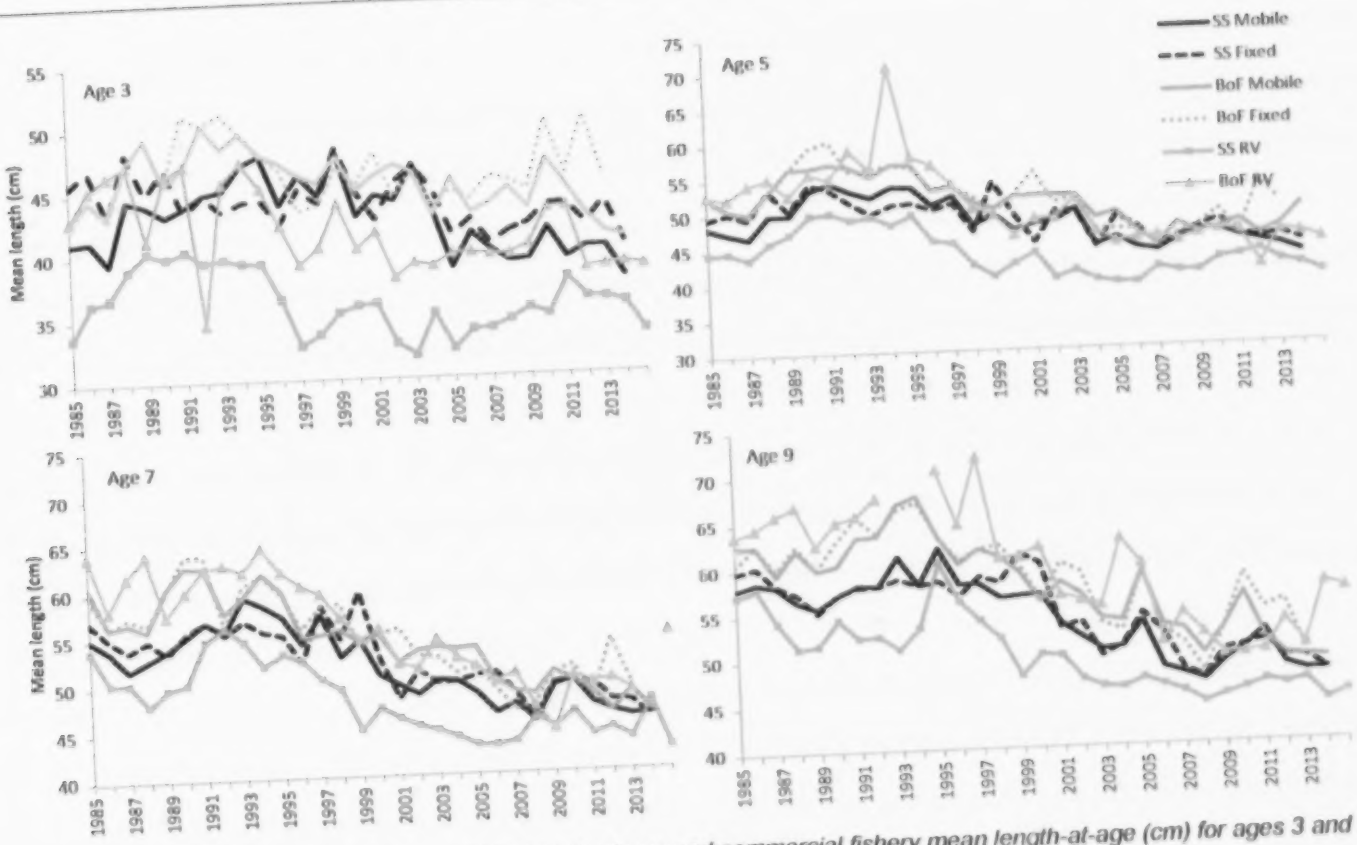


Figure 18. Comparison of the DFO Summer RV survey mean length-at-age and commercial fishery mean length-at-age (cm) for ages 3 and 5 (upper panel) and 7 and 9 (lower panel) for Haddock from the 4X5Y management area, 1985-2015.

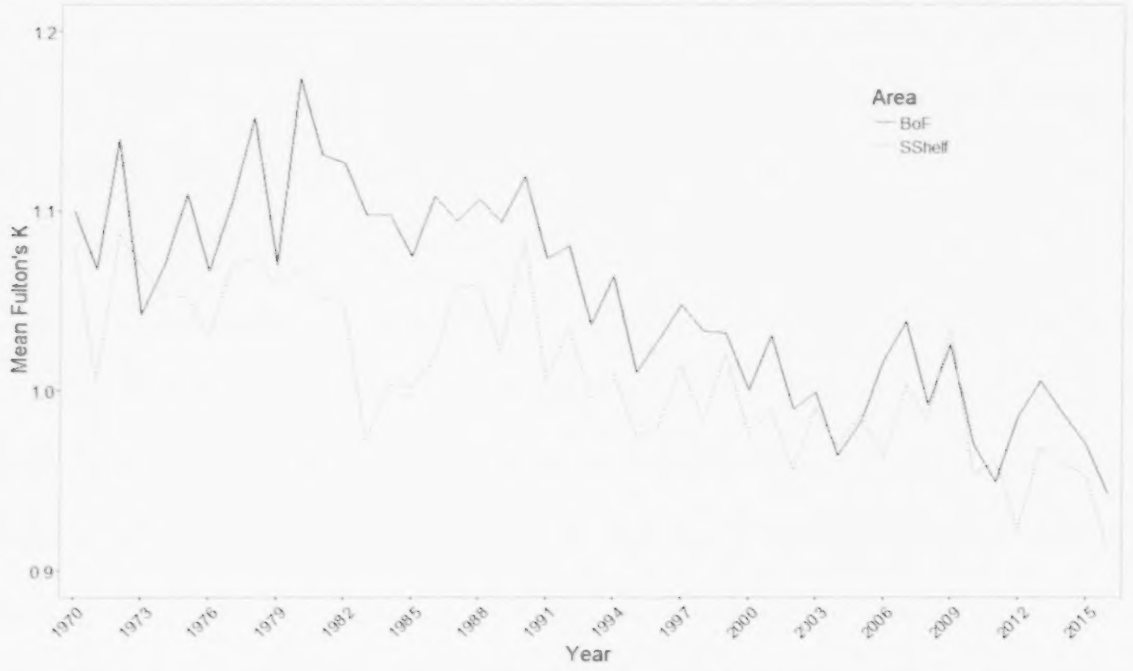


Figure 19. Comparison of Fulton's condition factor (k) (weight/length^3) for 28-55 cm Haddock from the Bay of Fundy and the western Scotian Shelf sampled during the DFO Summer RV survey, 1970-2016.

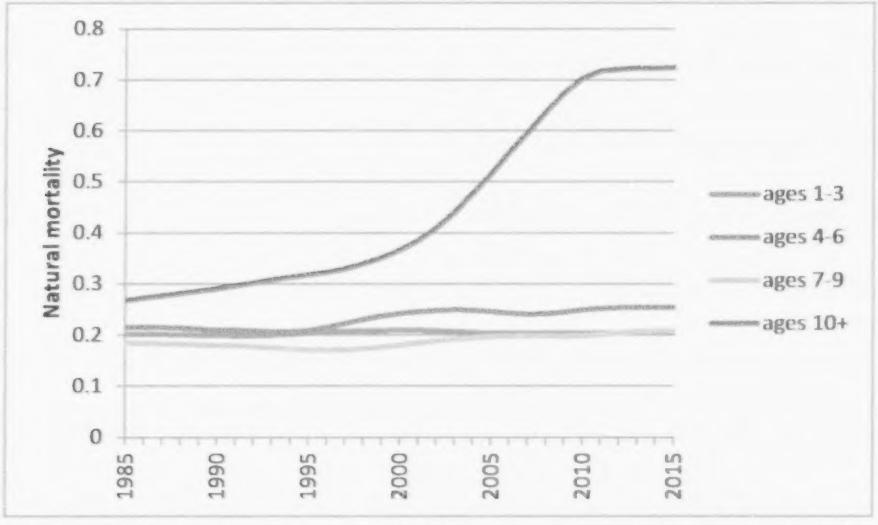


Figure 20. Natural mortality estimated for 4X5Y Haddock from a VPA model with time-varying natural mortality (M) with 4 age groups: 1-3, 4-6, 7-9, and 10+.

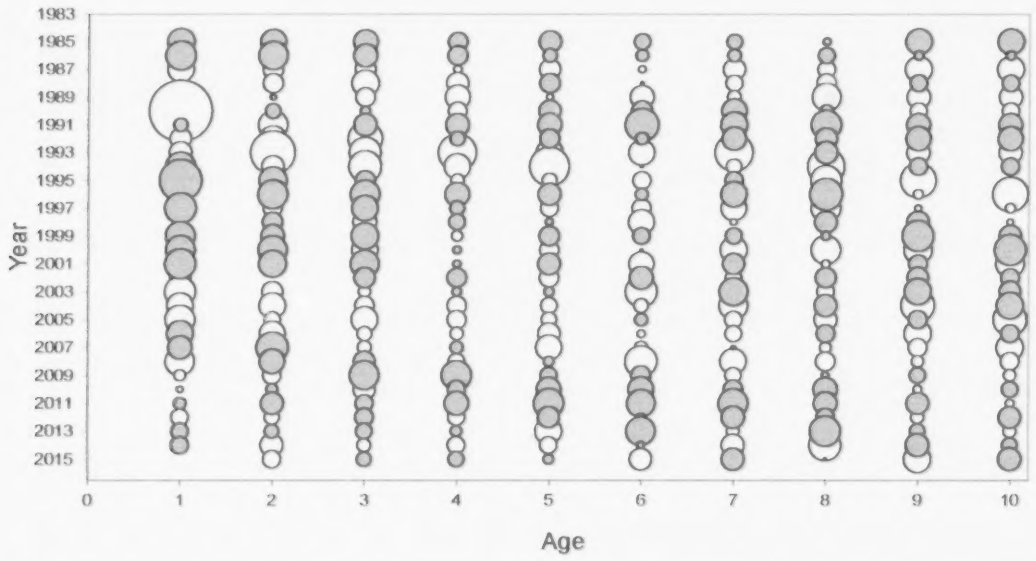


Figure 21. Residuals from the ADAPT VPA model formulation for 4X5Y Haddock of M fixed 0.2, except at 0.3, 0.6, and 0.9, for ages 10-11+ for the three 5-year times block (2000-2004, 2005-2009, and 2010-2015, respectively).

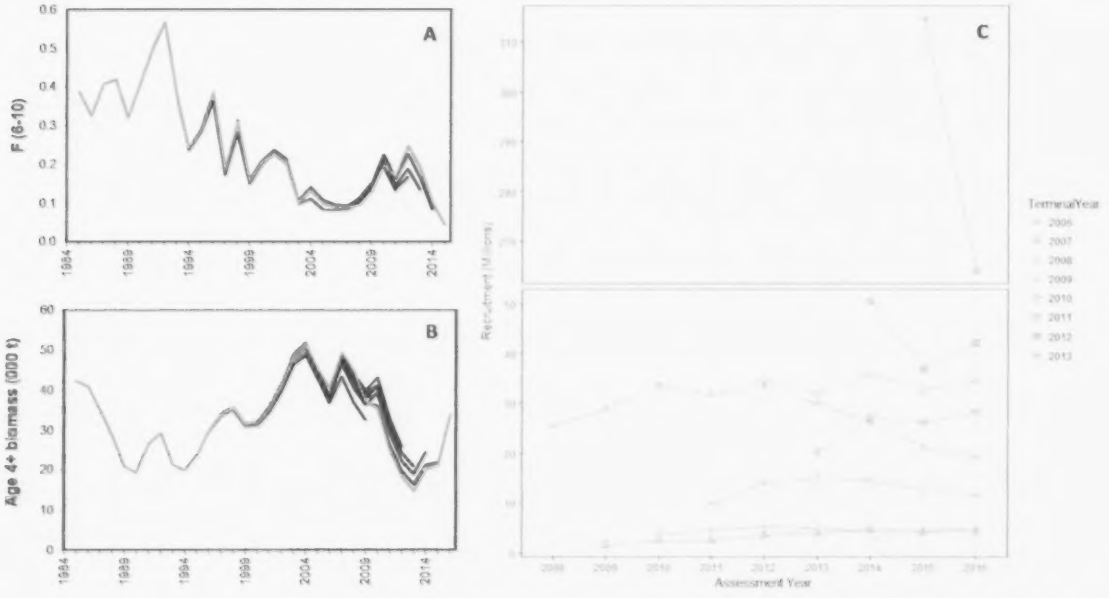


Figure 22. The retrospective analysis for fishing mortality (A), biomass (B), and the age 1 recruitment (C) from the ADAPT VPA model formulation of M fixed at 0.2, except 0.3, 0.6, and 0.9, for ages 10-11+ for the three time blocks (2000-2004, 2005-2009, and 2010-2015; respectively) for 4X5Y Haddock. Changes are relative to the 2016 assessment.

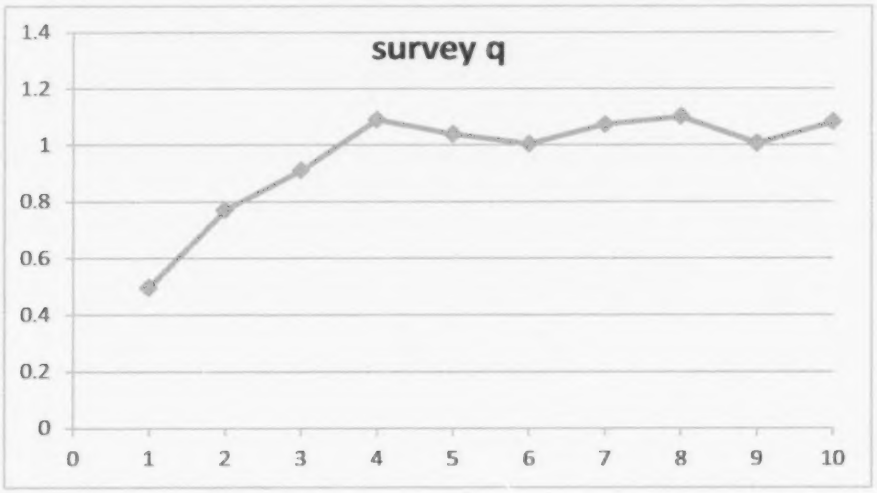


Figure 23. Survey catchability (q) at age estimated from ADAPT VPA model formulation of M fixed at 0.2, except 0.3, 0.6, and 0.9 for ages 10-11+ for the three time blocks (2000-2004, 2005-2009, and 2010-2015; respectively) for 4X5Y Haddock.

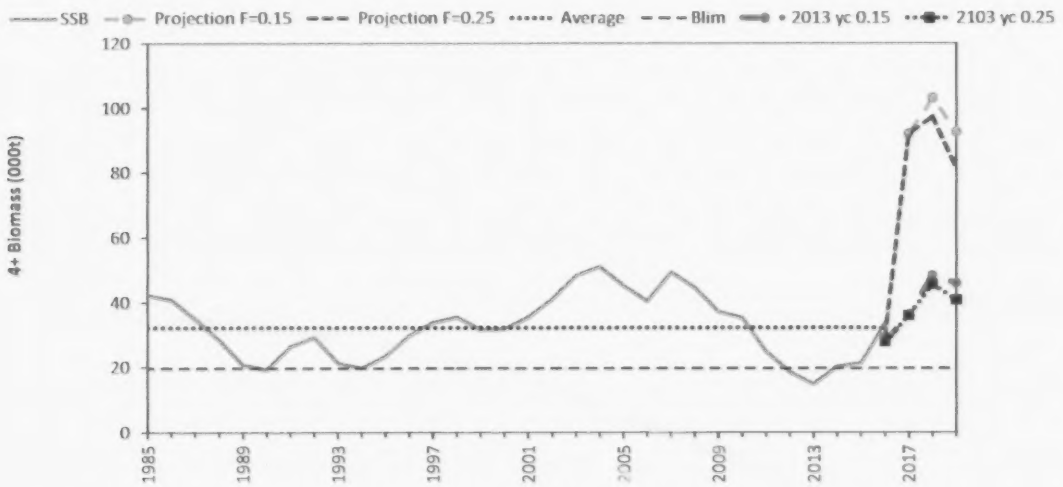


Figure 24. The model estimated 1985-2016 (solid blue line) and projected 2017-2019 (dashed biomass lines), 4+ biomass for 4X5Y Haddock. The established B_{lim} (black dashed reference line) is 19,700 t. The time series average 4+ biomass (black dotted reference line) is 32,258 t.

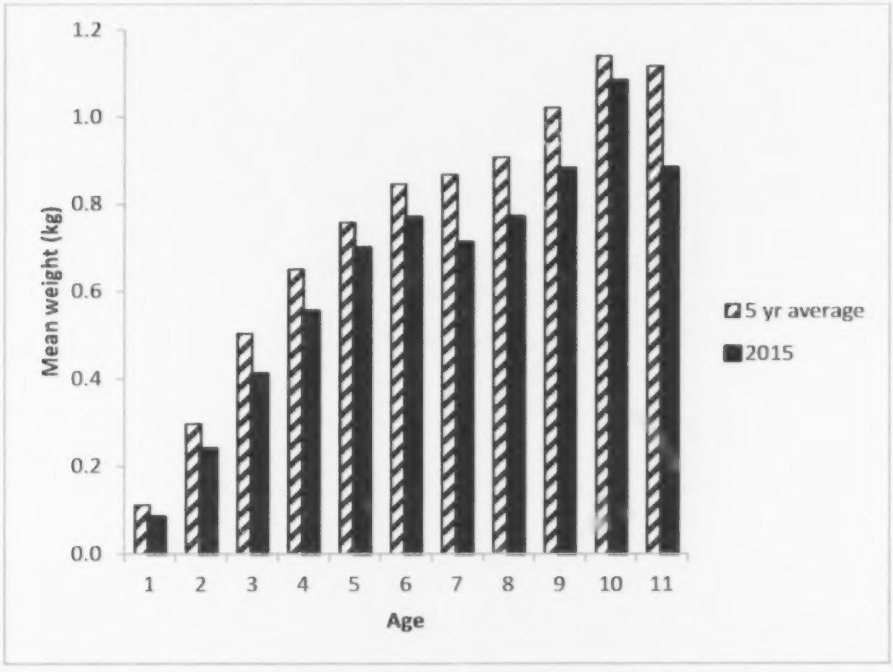


Figure 25. The most recent 5-year average, 2011-2015, survey average weight-at-age compared to the 2015 weight-at-age for ages 1-11 for 4X5Y Haddock.

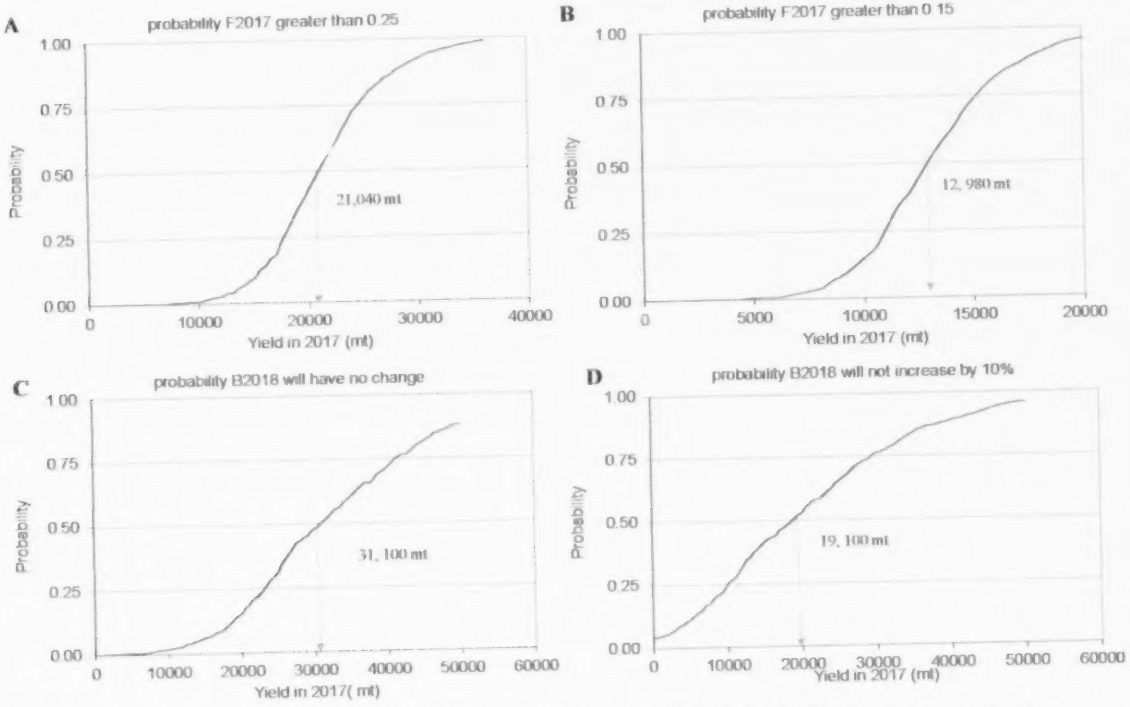


Figure 26. Stochastic projection to provide the risk of exceeding F_{ref}=0.25 (A), the risk of exceeding F=0.15 (B), and the probability that the 2018 biomass will remain stable (C), and the probability that the 2018 biomass will not increase by 10% under different catch values in 2017 for 4X5Y Haddock.

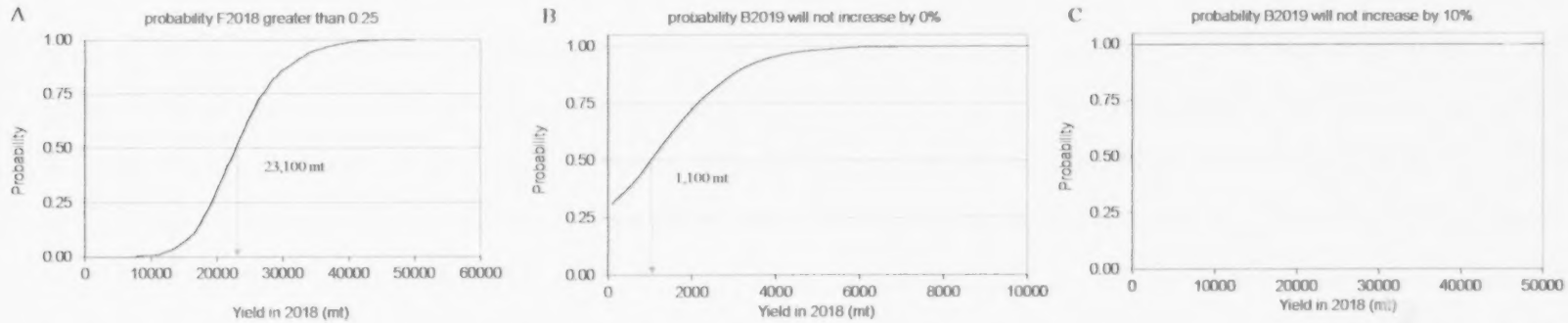


Figure 27. Stochastic projection to provide the risk of exceeding F_{ref}=0.25 (A), the probability of the 2019 biomass remaining stable (B), and the probability of the 2019 biomass not increasing by 10% (C) for different catch values in 2018 under an F=0.25 in 2017 scenario for 4X5Y Haddock.

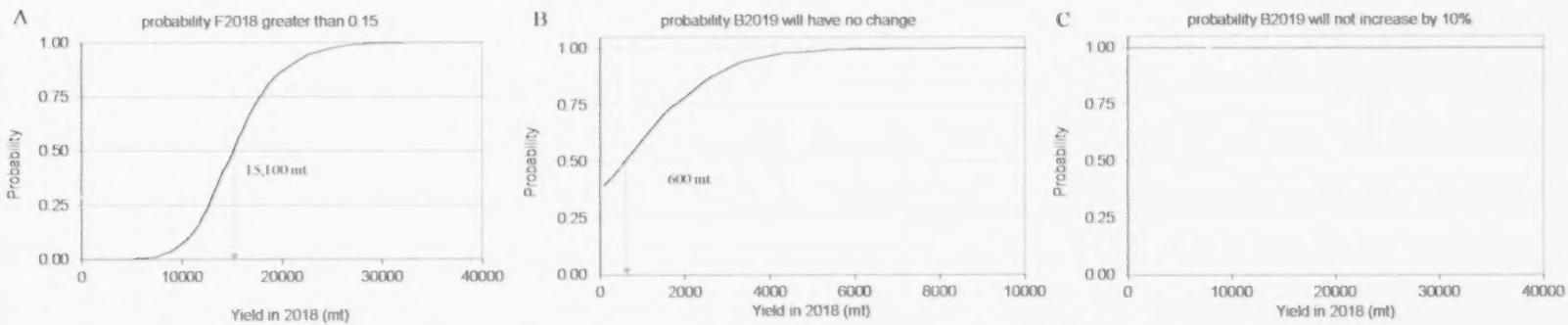


Figure 28. Stochastic projection to provide the risk of exceeding F=0.15 (A), the probability of the 2019 biomass remaining stable (B), and the probability of the 2019 biomass not increasing by 10% (C) for different catch values in 2018 under an F=0.15 in 2017 scenario for 4X5Y Haddock.

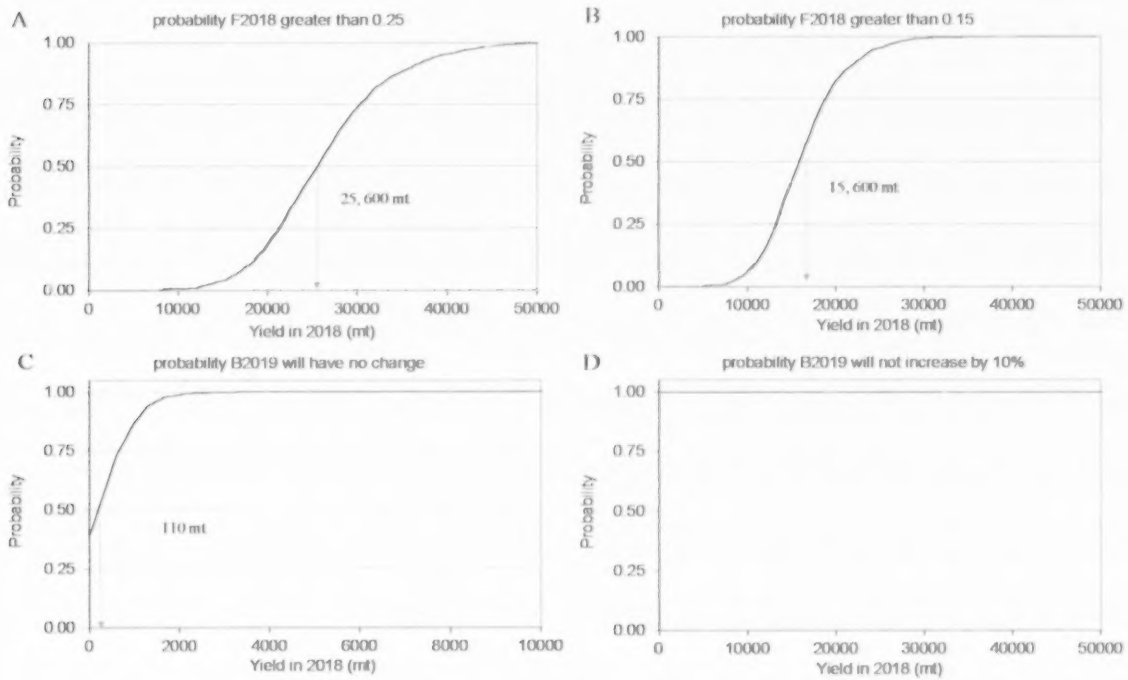


Figure 29. Stochastic projection assuming constant catch, 5100 t for 2017, to provide the risk of exceeding F_{ref}=0.25 (A), the risk of exceeding F=0.15 (B), and the probability of the 2019 biomass remaining stable (C), and the probability of the 2019 biomass not increasing by 10% for different catch values in 2018 for 4X5Y Haddock.

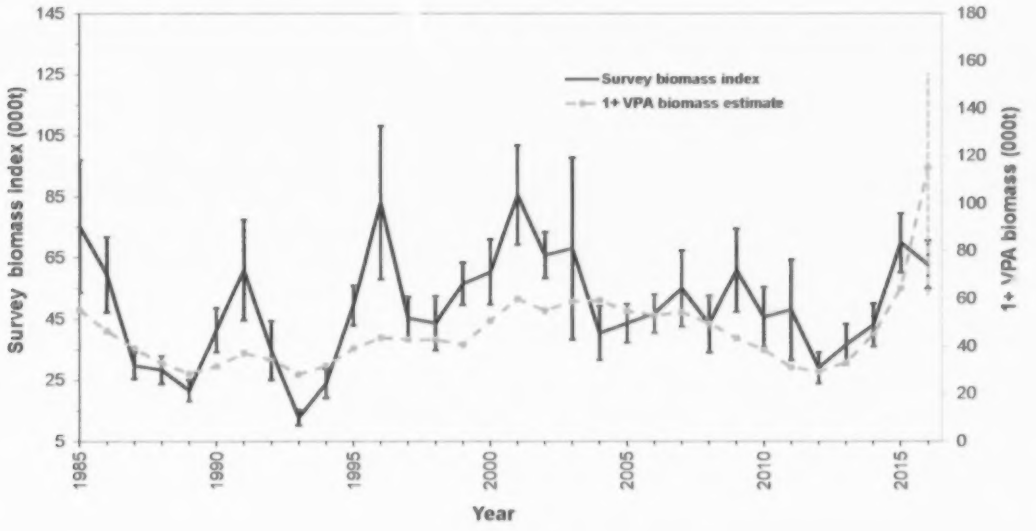
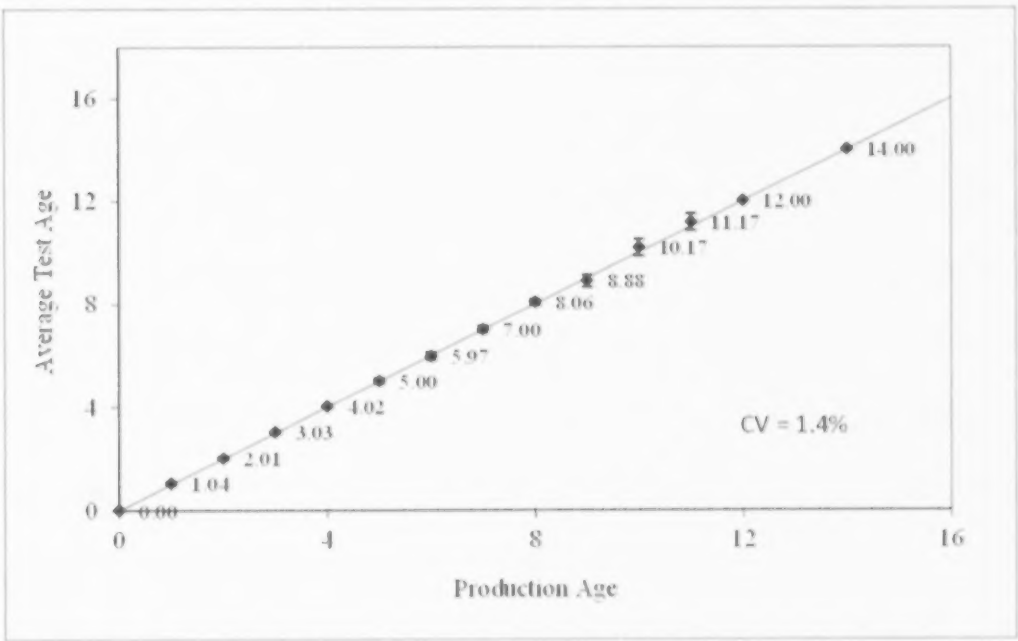


Figure 30. The total biomass index (000 t) ± standard error, including all ages, from the DFO Summer RV survey for 4X5Y (Bay of Fundy and Scotian Shelf combined) and the biased adjusted model estimated 1+ biomass for 4X5Y Haddock. The 95% confidence interval of the model estimated 1+ biomass was included for the 2016 run of the VPA. The biased model estimated abundance at Age 1 for 2016 was assigned as the most recent 10 years of geometric mean (excluding the exceptional strong 2013 year class) and no error was assumed for the recruitment at Age 1. Due to the data assumptions this figure should only for examining trends and should not be used for absolute numbers.

APPENDIX: RESULTS OF TESTING AGAINST REFERENCE COLLECTION

Test Age \ Production Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
0	3																	3
1		44	2															46
2		2	68	1														71
3			3	103	2													108
4				4	101	2												107
5					4	34	3											41
6						2	26	1										29
7							2	21										23
8								1	16	3								20
9									1	13								14
10										1	5							6
11											1	5						6
12												1	1					2
13																		
14															1			1
15																		
16																		
Total	3	46	73	108	107	38	31	23	17	17	6	6	1		1			477

Appendix Figure 1. Ages assigned by primary 4X5Y Haddock ager for reference collection ages.



Appendix Figure 2. Agreement between primary 4X5Y Haddock ager and the reference collection ages (0-14).